Biogeochemical Evaluation of Major Streams along the Eastern Flank of Mount Cameroon: Implications for Water Quality

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ABSTRACT

The Eastern flank of Mt Cameroon constitutes one of the richest drainage systems in the world. However, the surface waters on which the surrounding population depends, continues to witness pollution from anthropogenic and in some cases, natural phenomena. The major objective of this study was to conduct a biogeochemical evaluation on the quality of major surface waters (streams, rivers) to ascertain their suitability for human consumption, recreation and for the sustenance of their aquatic ecosystems. 9 water samples were collected and analyzed from 6 major streams and rivers running through heavily populated areas at the upstream and downstream. With the use of Rockwork software, multivariate statistical techniques were employed to group samples into hydrochemical facies in order to identify potential pollution sources. The results reveal a decreasing order of magnitude for cations: $Na^+ > Ca^{2+} > Mg^{2+} > K^+$. Meanwhile the anions the trend reveals a decreasing order as follows: $HCO_3^- >> Cl^- > NO_3^- > SO_4^{2-}$. The main water types of the area are NaK- HCO_3 and CaMg- HCO_3^-. While most of the samples have trace metal concentrations well below the WHO guidelines for drinking water, the Stone Quarters Stream (STQ) shows high concentrations of trace elements Fe, Mn and Al from geogenic sources. Most of the samples revealed generally low concentrations for trace metals as the total coliform counts exceeded the WHO guideline of zero (CFU)/100 mL. Rock-water reactions which leads to chemical weathering of silicates and human (anthropogenic) pollution which engenders microbial contamination are respectively the main culprits of surface water contamination. Most of the waters in their current state, are unfit for human consumption, recreation and ecological sustenance while still safe for irrigation with the exception of the STQ which appears unsuitably hazardous. The study further proposes institutional and technological remedies through which the problem can be addressed and mitigated such as effective stakeholder coordination, improved community awareness and waste collection processes, monitoring and enforcement, allocation of funds towards innovative solutions, expansion of sewage and water treatment facilities, water boiling and chlorination, and the provision of water filters.

Key words: Water quality, anthropogenic, contamination, pollution, trace elements, nutrients.

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TABLE OF CONTENTS

List of Tables

List of Figures

List of Abbreviations

CEF: Conserve Energy Future

CAMWATER: Cameroon Water Utilities Corporation

CVL: Cameroon Volcanic Hot line

DDT: Dichlorodiphenyltrichloroethane

ECAM: Enquête Camerounaise auprès des Ménages (Household Consumption Survey Cameroon)

ECFM: Environmental Challenges in Farm Management

ENN: Environmental Network News

FAO: Food and Agriculture Organization

FGN: Federal Government of Nigeria

GIS: Geographic Information System

GPS: Global Positioning System

IRD: Institute of Research and Development

IRGM: Institut de Recherches Géologiques et Minières

KfW: Kreditanstalt für Wiederaufbau (Reconstruction Credit Institute)

LAGE: Laboratoire de Géochimie des Eaux (Laboratory of Geochemistry and Water)

MDDELCC: Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques

MAFIC: Ferromagnesian Minerals

MDG: Millennium Development Goals

MINMEE: Ministry of Mines, Water and Energy

PANGIRE: Plan d'Action National de Gestion Integrée des Ressources en Eau

PCB: Polychlorinated biphenyl

pH: Power of Hydrogen

UCCC: United Cities and Councils of Cameroon

UNEP: United Nations Environmental Program

UNICEF: United Nations Children Emergency Fund

UNESCO: United Nations Educational and Scientific Organization

UNIDO: United Nations Development Organization

URT: United Republic of Tanzania

USEPA: United States Environmental Protection Agency

USGS: United States Geological Society

WHO: World Health Organization

1 INTRODUCTION AND BACKGROUND

Water, a precious natural asset and an indispensable resource for life, constitutes about 71% of total earth's surface (Annan, 2005; Lambi and Kometa, 2009). It is one of the most essential natural resources for the existence and development of life on earth (Rajagopal et al., 2010). Fresh water which is used in most vital human chores and activities makes up only 2.5% of which 98.8% is represented by ice and groundwater, and less than 0.3% is contained in the atmosphere, lakes, streams and rivers (Khatri and Tyagi, 2015). While 70% of fresh water is frozen in the Antarctica and Greenland, just one percent (1%) of the remaining fresh water on earth is available for extraction and human use (Corcoran et al., 2010). Surface water resources are increasingly being harnessed by the rising global human population for the production of many services and goods including but not limited to potable water, waste treatment and removal, fisheries, irrigation, industrial production, mining, transport and navigation, and recreation (Hairston and Fussmann, 2002). Over two billion people in more than 40 countries live in river basins that are currently undergoing significant water stress (FAO, 2011). The sitting and evolution of most forms and patterns of settlements from primitive to contemporary times have mostly been linked to the availability of water (Ako, 2012). Hence, water remains a finite vulnerable resource and a primary input in a wide range of production processes. This puts pressure on its availability in terms of adequate quantity and quality (URT, 2002). Being a high value public asset for all competing uses demands its careful conservation and sustainable utilization (World Bank, 2009).

Despite its enormous terrestrial abundance, the provision of good quality and sufficient quantity of water for human use remains a challenging problem the world over. To ensure the efficient and sustainable use of water for posterity, efforts should be made to protect and sustain water resources (Howard, 2002; URT, 2002). Due to the existence of multiple and often competing interests from various stakeholders, the sustainable management of water resources faces the difficult task of coordination. Hence balancing socio-economic needs and environmental concerns within an integrated framework on water management remains tricky (Kragt, 2013).

Being such an important resource for both domestic and industrial purposes, a closer inspection of our water resources today gives a rude shock (CEF, 2016). About a billion people today with a huge majority living in the developing world, lack access to safe and adequate water while about 4000 children die daily from water borne diseases (UNICEF/WHO, 2012; Virkutyte and Sillanpa,

2006), of which about 1000 perish daily in India alone (The Economist, 2008). Only 36% of the population of sub-Saharan Africa has access to safe drinking water (Central Statistical Authority, 1996). The sustained rise in the demand for adequate water, in terms of quantity and good quality for all human needs, exerts pressure on water (EEA, 2018). This means most sources of water supply are unfit for immediate consumption without some sort of treatment, thanks to heavy industrial and environmental pollution (Okonko et al., 2008). Hence, water in its clean and pure state is very rare on earth (Omole and Longe, 2008).

The contamination of our water supplies continues to be a preoccupying problem for all societies. Anthropogenic emissions of diverse chemical effluents accounts for the majority of environmentally critical problems we face today. These emissions are increasingly becoming environmental concern as they can potentially inflict irrevocable damages to the very ecosystem, which we depend on (Billa, 2009). Urbanization and urban planning, international trade, and a host of other anthropogenic activities continue to be culprit of physical, bacteriological, chemical and organic pollution of water resources (PANGIRE, 2009). The ease of dissolution of hazardous pollutants from both anthropogenic and natural sources greatly facilitates ground and surface water pollution. Natural sources of water pollution may be influenced or derived from natural disasters (volcanic eruptions, tsunamis, flooding, droughts, earthquakes), rock weathering, atmospheric deposition, while anthropogenic generated sources of water pollution involve domestic, municipal and industrial processes. These could originate from both point and non-point sources in both rural and urban areas (Khatri and Tyagi, 2015). According to Walker and Co. (2006), contamination of land as well as surface waters may or may not be deliberate. Deliberate contamination may involve the disposal of wastes from industrial products, animals, plants or even microorganisms with biocides, while accidental contamination presupposes the consequence of short and long-term aerial transport, flooding by rivers or seas, collision of the tankers and other automobile carriers of potentially toxic chemicals. Health risks from contaminated water can be derived from both microbial and chemical characteristics such as type of suspended particles, mineral elements, pH and ionic strength, mineral elements can variably influence the bacterial distribution in water (Lamrani Alaoui et al., 2007).

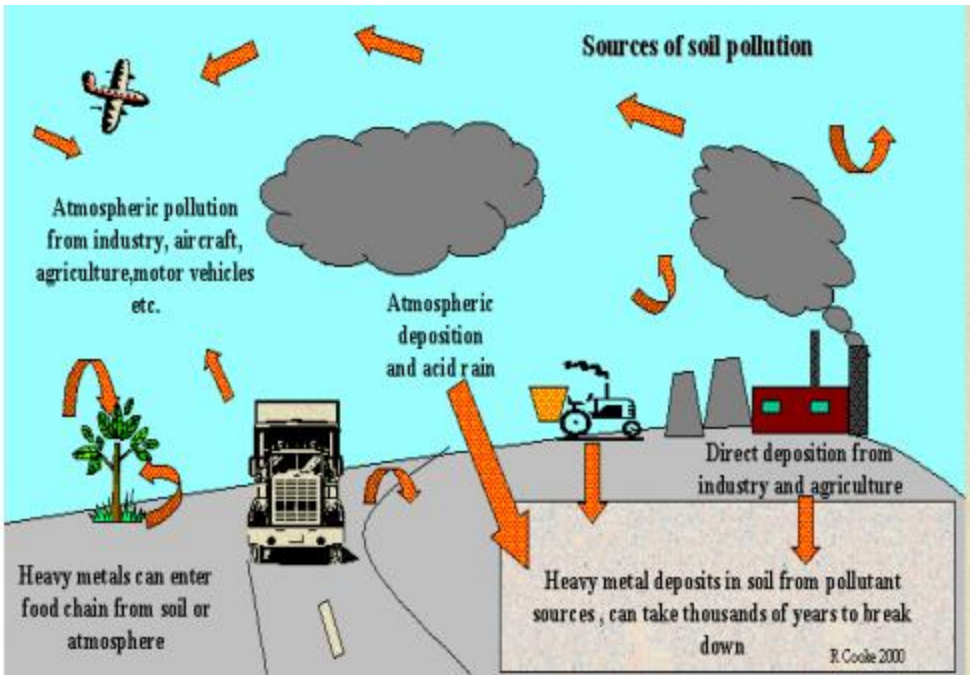

Figure 1. Major sources of heavy metals in soil pollution. Source: Environmental Challenges in Farm Management (ECFM UK, 2000)

About 4 billion daily cases of diarrhea lead to 2.2 million deaths annually worldwide, mostly within children under the age of 5 years. These are the result of microbial pathogens being transported by effluent water in mostly developing countries where hygiene and sanitation infrastructure either non-existent or is deficient (WHO/UNICEF, 2000; Moe and Rheingans, 2006). In recent years the transmission of pathogens by effluent consumable water has been the result of a slew of gastrointestinal outbreaks that have been reported worldwide (Hunter and Syed, 2001). To ensure that water is potable and safe for drinking it must comply with certain prescribed microbiological, physical and chemical standards (Tebutt, 1983). Water is a scarce resource whose usage by man must be protected through laws, policies and regulations (FGN, 2000). In order to assess the suitability of water quality for both environmental safety and human consumption, it is being analyzed physico-chemically and biologically over a set of prescribed guidelines (Khatri and Tyagi, 2015). While the ultimate goal of this work will largely dwell on surface water contamination, it is essential to highlight the influences of groundwater contamination on surface water as both systems are integrally connected entities within the hydrological cycle.

1.1 Groundwater Contamination

Groundwater contamination continues to be a persistent environmental and human burden. It largely involves the release of man-made pollutants such as gasoline, oils, fertilizers, and other chemicals into groundwater, rendering it unsafe and unfit for human use, and to the environment (The Groundwater Foundation, 2015). These can be the result of activities such as agriculture, industry, urban development, and increasing exploitation of water resources and atmospheric input (Chan, 2001). Groundwater quality on a regional scale is largely determined by natural processes such as lithology, groundwater speed, quality of reloaded water, and interaction of water with soil components and rock, and interaction with other types of aquifers (Khatri and Tyagi, 2015). The quality of both ground and surface water depends on natural and human factors which may occur separately or in combination (Stark et al., 2000). The natural processes that affect groundwater quality are volcanic eruptions, weathering and rock-water interaction, seasonal variation, crater lake gaseous dissolution, evapotranspiration, natural soil leaching processes, hydrological factors leading to run-off and flooding and biological processes that lead to modification of physical and chemical composition of water (Khatri and Tyagi, 2015). In many parts of the world, groundwater contamination occurs from naturally occurring contaminants, such as arsenic or fluoride, sulphates and heavy metals. Naturally occurring arsenic, uranium, radium, radon and manganese have been found at elevated levels in some bedrock groundwater supplying drinking water wells, and hence duly pose potential environmental and health hazards (ENN, 2012).

In Bangladesh for example, 25% of shallow aquifer wells in the Ganges Plain of northern India and Bangladesh are severely contaminated by arsenic at hazardous elevated levels. According to Pawer and Bhosale (2015), this occurs because the organic matter in the aquifer sediments promotes anaerobic conditions suitable for the microbial dissolution of iron oxides. Hence with rising pH, arsenic which strongly binds to iron oxides gets released into groundwater. In many parts of the world, fluoride is another contaminant that has been found in dangerously high levels in groundwater which is ultimately being used for drinking. In areas where this occurs, skeletal and dental fluorosis is prevalent (WHO, 2004).

1.2 Surface water contamination

Surface water refers to water that rests on the earth's surface such as ocean, ponds, wetlands, river, stream and lake, and can be contrasted with groundwater and atmospheric water (Young and Bredehoeft, 1972). Meanwhile freshwater constitutes water on the Earth's surface including ice sheets, glaciers, icebergs as well as groundwater and underground streams (USGS, 2016). Fresh water is generally characterized as having low concentrations of dissolved salts and other total dissolved solids. The term specifically excludes seawater and brackish water although it does include mineral-rich waters such as chalybeate springs. Figure 2 represents the percentage distribution of the different global surface water components.

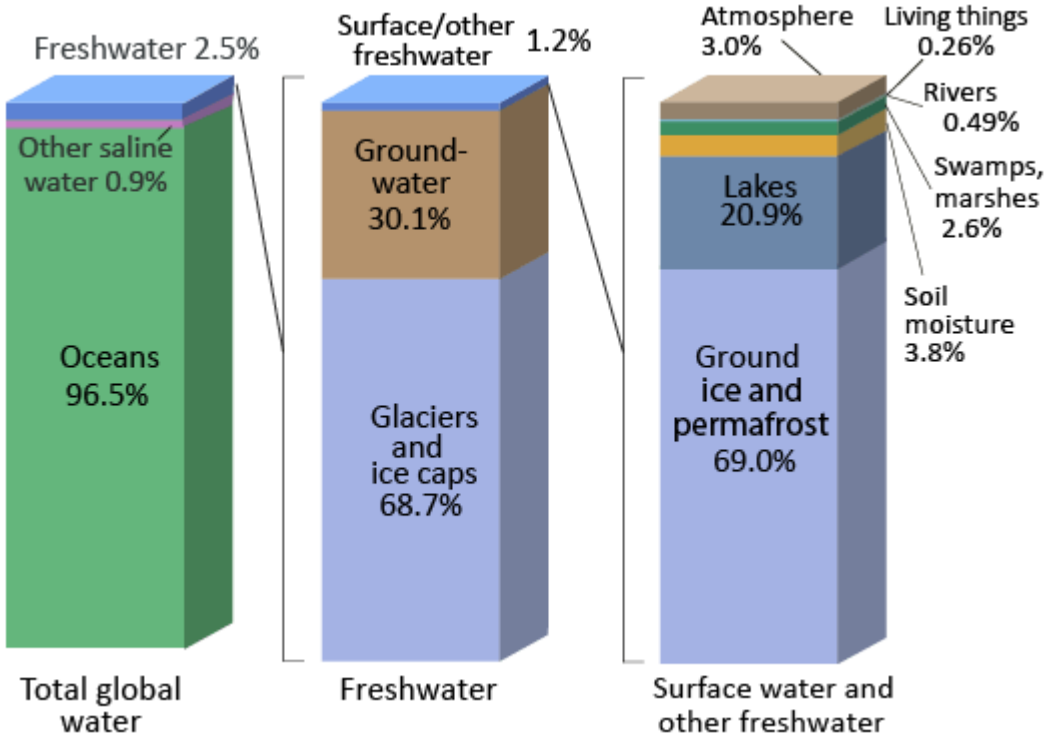

Figure 2. Distribution of Earth's Water. (Source: USGS, 2016)

The non-saline portion of surface water which constitutes part of fresh water and with the exclusion of seas, oceans, brackish water, is fed by replenishments from precipitation and groundwater. This fresh water resource can be lost by evapotranspiration, leaching into the sea, infiltration and seepage into ground-water or being used by man (Fetter, 2000). Surface waters represent viable habitats

for the study of biophysicochemical interactions and other related dynamic processes occurring within the terrestrial ecosystem (Hairston and Fussmann, 2002).

Due to their use for waste water and other wastes' disposal in most areas of the world, surface waters have become increasingly susceptible to pollution (Carpenter et al., 1998), and the quality of surface water in a particular region is influenced by both anthropogenic and natural processes (Jarvie et al., 1998). While the vast majority of surface water contamination emanates from human activity, it should be noted that natural contaminants to surface water should be similarly anticipated and addressed by water treatment prior to consumption (Viqua, 2016). Though often considered as two separate entities, surface and groundwater both constitute part of an interrelated system and must be managed as such especially when the supply for water cannot meet demand (Fetter, 2000). The next chapter will outline the current issues and proffer an elaboration on the prevailing problems into both anthropogenic and natural origins.

1.3 Objective of Study

The main objective of this work is to investigate and provide knowledge on the sources, processes leading to, and the extent of surface water contamination on the Eastern flanks of Mount Cameroon.

1.3.1 Specific Objectives

This would evolve around the following specific objectives.

a) To determine whether the headwaters being consumed by about 2/3 of the local population, is safe for drinking, for other domestic and recreational uses in the wake of recent recurrent volcanic phenomena and anthropogenic contamination.
b) To ascertain whether the recent concerns of human contamination, raised from the consumption of some of these headwaters pose water quality challenges potentially related to natural volcanic phenomena.
c) To investigate the prevailing biological, physical and geo-chemical parameters of the major surface water bodies and to provide key stakeholders (national and local governments, NGOs and traditional authorities) with key data to craft policy towards efficient and safe waste-disposal strategies aimed at protecting these waters and their containing biota from further pollution.

d) To establish the hydro-geochemical facies in order to identify contamination sources through the analyses and characterization of the various parameters using multivariate statistical methods. Hence the goal is to identify and understand the prevailing geochemical processes and microbiological phenomena controlling surface water quality in the areas of concern.

It should be noted that, the local population especially in the rural areas greatly depends on the water resources for food and other diverse socio-economic needs. The achievement of the objectives would greatly help in the provision of data for pollution mitigation and more broadly, towards the sustainable management of these water bodies and their resources.

1.4 Thesis Organization

This thesis comprises six chapters as follows:

Chapter 1: Introduction and background

Chapter one presents and elaborates on the distinctions between surface and groundwater contamination. It also outlines the objectives of the study as well as the general thesis organization.

Chapter 2: Literature Review

This chapter begins with a description of the different (anthropogenic and natural) parameters through which water gets polluted. It further explores and elaborates on the research question as well as the rationale of the study.

Chapter 3: Introduction to Study Area

This chapter presents the biophysical environment and the socio-economic promoters of pollution in the study area.

Chapter 4: Materials and Methodology

This chapter elaborates on the resources, tools and procedures that were employed both in the field and in the laboratory, in order to realize the goals of the study. These included sampling and analytical methods as well as health risk assessments.

Chapter 5: Results and Discussion

This chapter presents and discusses the results from both field and laboratory analyses. The results are presented in figures, tables and histograms.

Chapter 6: Conclusions and Recommendations

This chapter provides conclusions on the results and discussion as it pertains to water contamination issues in the area. The chapter further highlights the limitations, opportunity for further studies, outlines some recommendations to mitigate and alleviate the prevailing problem
This study ends with references and an appendix comprising further presentation of results.

2 LITERATURE REVIEW

Water can be contaminated either overwhelmingly through human influences or naturally. Hence, this chapter will focus on the formulation of the problem or issues at the core of this work, into both anthropogenic and natural pollution.

2.1 Anthropogenic Context

The apparent abundance of water does not translate into its relative availability in most of Sub-Saharan Africa, as this region of which Cameroon is part of, continues to face serious water scarcity problem (Lactem, 2009). The United Nation's Rio+10 Assessment report on Cameroon further stipulates that rough typology from some recent related studies on the following parameters like biochemical oxygen demand, nitrates and phosphate contents, have all shown a significant overall contribution to industrial pollution particularly from the agro-industrial industries (WHO/UNICEF, 2008b). A report on the state of water pollution in Africa revealed serious chemically contaminated water systems in Cameroon, by especially pesticides. Some of these products, emanating from industrial plantations are lindane and aldrine, DDT as well as contamination from PCBs (UNIDO, 2002). Many peri-urban dwellers in Cameroon lack access to safe drinking water (WHO/UNICEF, 2008b).

Water pollution is inextricably linked to both land and air pollution in terms of overall exposure patterns and parameters (Billa, 2009). In Cameroon, the rapid increase in urban population, followed by poor and inadequate water supply and sewage treatment facilities, are the results of pollution of surface waters. This has led to surface waters being directly or indirectly used as disposal sites (Figure 8) for various types of wastes thereby adversely altering their intrinsic biological, physical and chemical properties (Djuikom et al., 2006; Patil, 2012). Hence, biological water quality is essential as it provides information on the presence and concentration of disease-causing microbes (pathogens) (WHO, 2011). Waterborne pathogens remain the primary cause of morbidity in many developing nations (Servais et al., 2007), and the outbreak of waterborne diseases can potentially cause simultaneous infection on a community scale (WHO, 2011***).*** Sedimentation, sewage contamination, agrochemical contamination and other anthropogenic stressors can lead to eutrophication, acidification, toxic algae blooms and the proliferation of enteric bacteria, rendering the water unfit for direct human consumption, incidental ingestion or in some extreme cases, body

contact (Biradar et al., 2014*)* In many urban areas of Africa, the breakout of an epidemic from surface water contamination, might engender a rapid proliferation due to the cultural, tribal and national diversity of the populations A seasonal monitoring of the variation of groundwater biological quality is necessary in the practice of groundwater quality assessment and resource management in urban areas (Akoachere and Ngwesse, 2017).

There have been recent recurring reports of outbreaks of water-borne related health hazards from village locals drinking spring water from remote villages up on the flanks of Mount Cameroon where potable water is lacking. Fouépé et al. (2011) postulate that in developing countries such as Cameroon where the availability of pipe-borne water is currently at about 35% of city dwellers, the vast majority of rural and other city dwellers use surface water for many chores and other domestic activities. A Cameroon government's statistics reveals that only 30% of the total national population of about 25 million has access to pipe-borne drinking water (Valentine, 2014). Hence the country lags behind in meeting the Millennium Development Goals (MDGs) target on water and sanitation especially in rural communities (Ako et al., 2010).

These water systems constitute springs, streams and rivers upon which the riverine population consumes directly for drinking as well as for other domestic and recreational purposes. However, intense human activity along the area creates conditions necessitating the possibility of anthropogenic contamination. The eastern flank of Mount Cameroon is overlain with very fertile andosols which attract dense population settlements followed by major and minor industrial and commercial activities as well as intense upstream agriculture. These operate in the form of extensive agro-industrial plantations with the application of chemical fertilizers and pesticides. With a corresponding poor to in some areas inexistent waste and sewage disposal methods, anthropogenic contamination remains the most likely pathway to surface water pollution. Anthropogenic loading onto these streams from mostly organic and waste disposal, could be threatening the very riverine population and the ecosystem.

Table 1: Proportion of households with no access to safe drinking water (ECAM, 2001)

Region	Percentage household population with no access to safe drinking water in 2001
Adamawa	59.9
Centre	37.7
East	86.6
Far North	58.1
Littoral	26.3
North	61.8
North West	51.6
West	71.3
South	67.4
South West	24.9
Cameroon	**49.5**

2.2 Natural Context

Due to the prevalence and significance of water pollution from anthropogenic sources, it is permissible to understand the heavy focus on this aspect of water pollution. However, the natural causes of water pollution, though globally limited in time and space, can also cause potential hazards to human health and the ecosystem especially in rural areas where scarcity of potable water supplies abound. Natural sources of water pollution have been documented not only from the consumption of virgin sources like springs in most rural areas, but also in the mountainous watersheds of Peru and the delta plains of Bangladesh. According to Fortner et al. (2011), the exposure of

sulphide-rich outcrops from glacial retreat and the poor water quality of the headwaters of the Cordillera Blanca in Peru, result in very low pH sulphurous waters almost unfit for dermal contact. Chemical weathering of rocks is one of the most potent natural processes through which ground and surface water systems can become contaminated and thereby unfit for domestic consumption. The chemical composition of ground and surface waters is dependent on a range of factors ranging from hydrogeological, meteorological and biological. According to Pönkka (1981) and Rönkä (1983), ground and surface water geochemistry is being influenced by geological factors resulting from water–rock interactions in aquifers. This is further dependent on the rock type, the type of weathering of the particulate minerals as well as seasonal differences in weather conditions, run-off volumes and water levels.

Basaltic Rock + CO_2 + H_2O ➔
Alumino-silicates + H_4SiO_4 + HCO_3 + Ca^{2+} + Mg^{2+} +Na^{+} + Sr^{2+} + Fe^{2+} ……. …….(1)

According to a recent U.S. Geological Survey study on New England, potentially harmful levels of naturally occurring arsenic, lead, uranium, radium, radon and manganese and fluoride have been found in some bedrock groundwater that supplies drinking water wells in this region of the United States (ENN, 2013). The Ganges Plain of northern India and Bangladesh are another renowned example where severe natural groundwater contamination by arsenic occurs impacting about 25% of water wells in these areas. The heavy presence of organic matter from sediments in these delta regions engenders anaerobic conditions in the aquifer, facilitating iron oxides dissolution and release of its usually strongly bound arsenic into groundwater (ENN, 2013). Also, volcanogenic acidity of surface waters derived from acidic gases and thermal waters releases have been reported with recent volcanic eruptions from the 1985, Nevado del Ruiz volcano in Colombia (Parnell and Burke, 2010).

Geological forces like volcanic eruptions have beneficial effects due to their formation of spectacular mountains chains and architecturally significant rock quarries, hydrothermal hot springs and ore deposits of economically important minerals (gold, silver, copper, aluminum among others), as well as fertile volcanic soils characteristic of volcanic areas (ENN, 2012). However, during the course of geologic time, the resulting sustained leaching of trace metals into the groundwater can pose a threat to human health (ENN, 2013). Besides the effect on groundwater, the immediate aftermath of a violent volcanic eruption can contaminate surface water systems from the spewing

of ash and smoke containing poisonous gases (SO_2, CO, HCl, HF, H_2S) which then deposits on land and consequently is washed by rain on to seas, lakes, rivers or directly on these water bodies. Volcanic eruptions are also responsible for the creation of acid rain which can end up in surface waters thereby posing threat to aquatic life by increasing the pH of the aquatic environment (Vegeris, 2013).

The groundwater containing dissolved minerals comes into contact with the uprising cooling magma and is being heated. It can rise to the surface along rock fractures to form a thermal spring, fumarole, or geyser used to heat homes and businesses, or may later deposit within fractures and rock crevasses and then issues as springs with potentially high levels of dissolved harmful metals (Vegeris, 2013). Associated problems resulting from volcanic eruptions which may or may not lead to water contamination are; earth greenhouse effect, mudflows and flash floods, landslides and rock falls, small earthquakes; ash fall and acid rain and tsunamis. Dental fluorosis has been reported in localities around the São Miguel Volcanic Island (Azores, Portugal). This is due to high fluoride content being leached from weathering within aquifers containing volcanic silicate rocks (Cordeiro et al, 2012). Meanwhile elevated levels of heavy metals and F^-, SO_4^{2-} , and Cl^-, above drinking and surface water standards, all characterized the surrounding rivers and melted snow of the Bárðarbunga volcanic eruption in East Iceland with potential adverse effect on the salmon population.

In areas of Africa and Asia, there have been releases of dissolved poisonous gases from crater lakes of active volcanic phenomena. Lake Ijen in Indonesia known as the largest most acidic Crater Lake in the world, has released highly metallic enriched and extremely acidic (pH <1) water down-stream into rivers (Löhr et al, 2005). The 2010 volcanic eruption of both Mounts Nyamuragira and Nyiragongo in Eastern Democratic Republic of Congo (DRC), affected potable water resources which led to cases of clinical discomfort (nausea, indigestion, vomiting, bloating among others) from the local inhabitants – emanating from rock-water interactions and acidic aerosol deposition (Cuoco et al, 2013). Meanwhile the deadly lakes Nyos and Monoun of Cameroon have released fatal concentrations of CO_2 and other toxic gases suffocating and killing many human and animal lives in 1986 and 1984 respectively (Lee et al., 1994). Following the recent volcanic eruptions on Mount Cameroon there have been reports of clinical symptoms of contamination from the local riverine population along the flank of the mountain that use these headwaters for drinking (Lactem, 2016).

The flanks of Mount Cameroon constitute one of the most hydrologically rich watersheds in Africa. With current population estimates of about 450,000 living around the volcano (Ako, 2016) and with a corresponding density of 120 people/km^2, the area boasts a population density above the national average of 34 people/km^2 (Thierry et al., 2008). It is covered with lush vegetation, lakes, rivers and streams that encompass a rich ecosystem with most settlements and economic activities concentrated on the eastern flanks as seen in Figure 3.

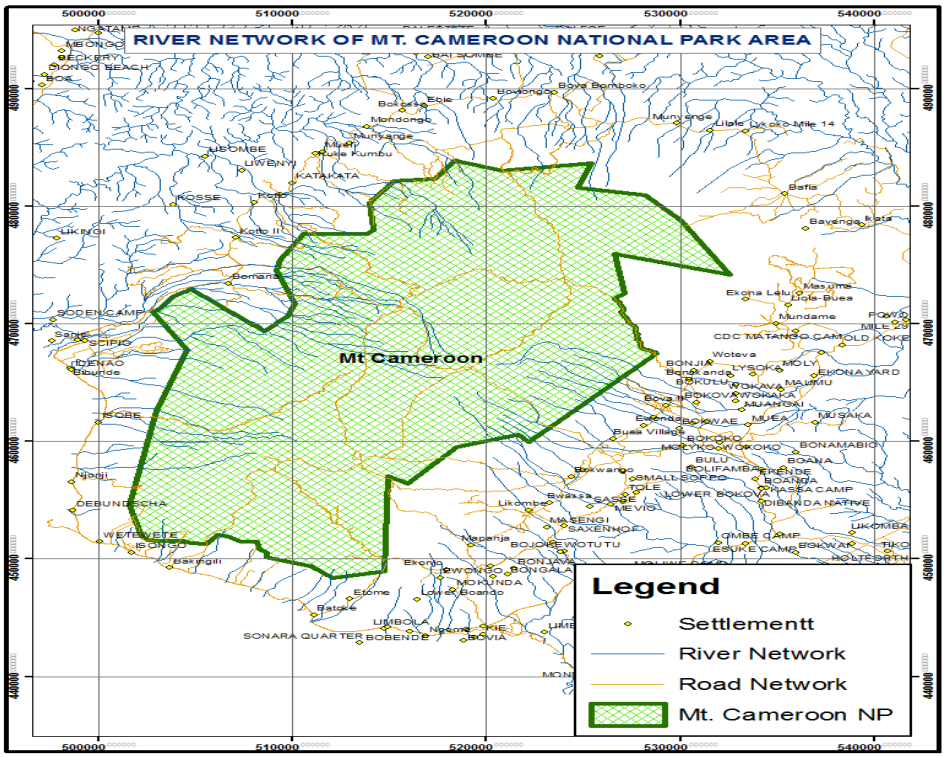

Figure 3. Mt. Cameroon watershed area (Source: GIZ/KFW, 2014)

Mount Cameroon is a shield volcano that forms part of the Cameroon Volcanic Hot Line (CVL), an active volcanic belt of 12 other active volcanoes traversing the country in a SW – NE fashion from the Atlantic Ocean (Lee et al., 1994).

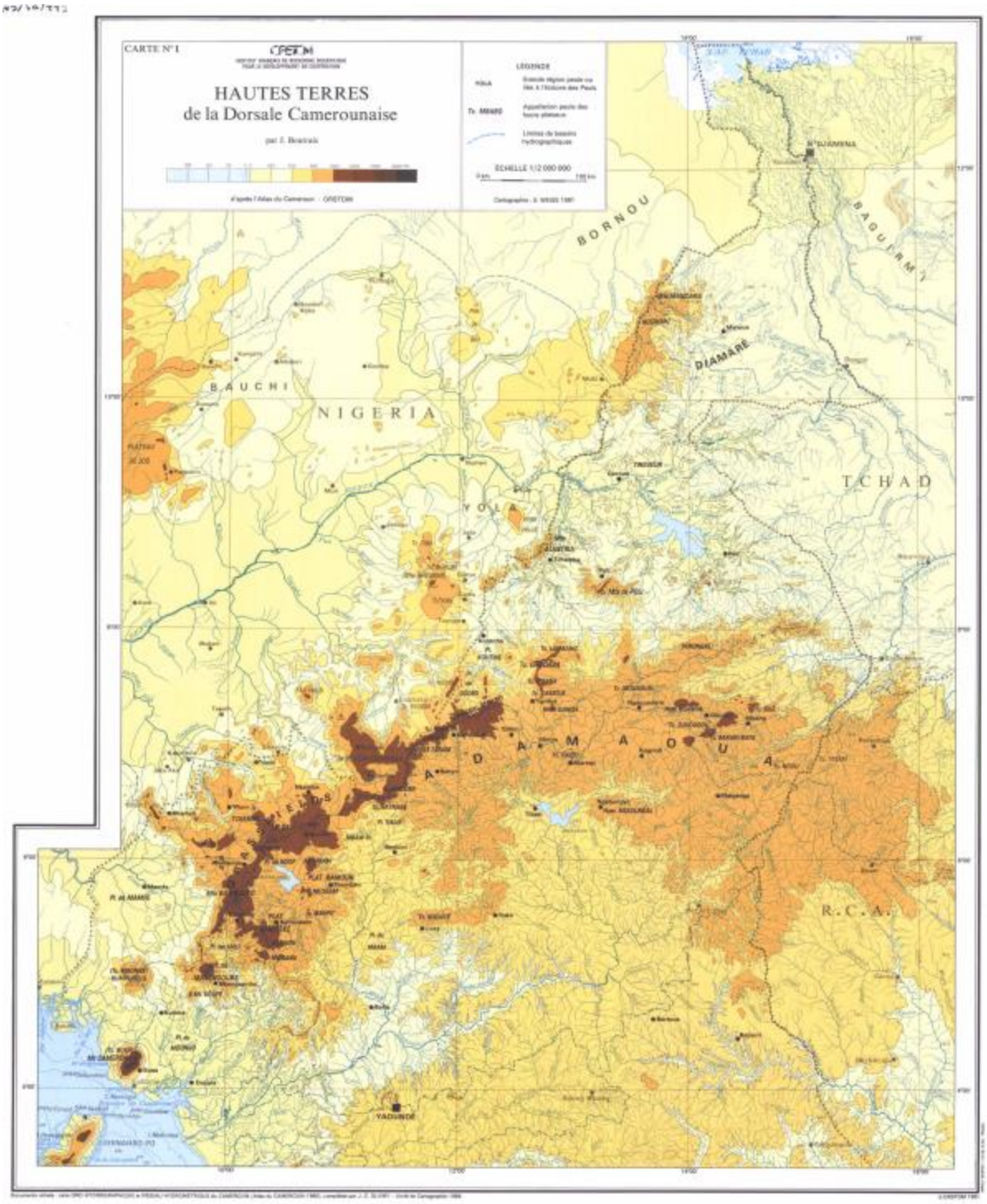

Figure 4. Highlands of the Cameroon Volcanic Hot Line (Source: Boutrais, IRD, 1996)

The massif is underlain by a predominantly ferromagnesian (MAFIC) basaltic and tephra bedrock emanating from a shield Strombo-Hawaian volcanic phenomena (Chauvel et al., 2004; Benedette et al., 2003). High elevation and sea proximity, extreme variable moisture conditions between the

seaward and landward flanks of the volcano only favours chemical weathering (Bulourde, 2001). The subsoil is composed of mainly andosols and a higher water storage capacity, resulting in a dense network of springs and headwaters (Ako, 2016). A combination of intense meteoric processes from a heavy global rainfall (2nd only to Cherrapunji, India), high temperature and humidity and relatively soluble and alterable substratum favours chemical weathering, ion exchanges and increasing rock-water interactions. These processes coupled with anthropogenic influences, give rise to various water types that produce distinct hydrogeochemical facies.

Figure 5. Aerial representation of Mt. Cameroon massive and Equatorial Guinea Republic (Source: Bérenger, 2016)

The CVL tectonic fault line, of which Mount Cameroon is part of, incorporates Lake Nyos - World's Deadliest Lake (Guinness World Records, 2008) and Lake Monoun, whose surrounding groundwater water resources are acidic and unfit for drinking and other domestic purposes (Kamtchueng et al, 2016). The local population around this volcanically active fault line obtains water from wells, springs and boreholes being used for drinking and for multiple forms of domestic, industrial and other subsistence forms of livelihood (Lactem, 2009). The streams particularly

play an important part in that they flow through both rural and urban communities that use them for domestic industrial as well as for recreational purposes like swimming in which case, incidental ingestion and dermal contact are important. Within these communities, the streams remain an important conduit for contamination as the occurrence of water-borne diseases remains rampant and endemic (GTZ, 2006).

2.3 General Research Question

What are the qualitative and quantitative characteristics of major streams flowing through heavily populated communities along the eastern flank of Mount Cameroon?

2.3.1 Specific Research Question

The following research questions would guide the objectives of this study.

a) What are the geochemical and microbial parameters of these streams flowing through major population hubs along the eastern flank of Mount Cameroon?
b) What are the sources of contamination of these streams and rivers?
c) What is the suitability of these surface water systems for human use, contact and for the sustenance of their containing ecosystem?

2.4 Rationale of the study

Cameroon is blessed with abundant water resources making it the second most hydrogeologically rich nation in Africa a cumulated quantity of available water resources estimated to be around 322 billion m^3, after the Democratic Republic of Congo (DRC) (Mafany and Fantong, 2006). Like many other societies today, the principal challenge Cameroon faces is not so much access to water, rather the access to suitable water for human consumption (drinking, household chores, recreation). Hence, the quality of water resources in Cameroon like elsewhere becomes the main focus of attention (Temgoua, 2011).

Water pollution is inextricably linked to land pollution. Quoting from the study on soils and land pollution in Ghana, “The nation that destroys its soils destroys itself”. Land pollution and

degradation is the gradual process by which the natural state and quality of land is destroyed through the activities of man, to the degree the natural environment becomes insufficient to support living organisms (Soils and Land Pollution in Ghana, 2008).

Due to rapid increase in population of the major towns along the Eastern slope of Mount Cameroon, the resultant anthropogenic activity and land use changes have adversely affected fresh water resources in the region (Shrestha, 2014). Apart from deep wells, springs and boreholes, the local population continues to obtain drinking water from streams which simultaneously serve as dumping sites for a variety of municipal wastes (Lactem, 2016). The percentage of the population with access to pipe-borne water albeit with low standards, is just about 57%, meanwhile about 9% of all the villages in the Mount Cameroon region do not have any water supply (Page, 2000). Consequently, Mount Cameron region has recorded a series of cholera epidemics in the last years (222 cases in 2004, 1112 cases in 2005, 255 cases in 2006) (GTZ, 2006). This scenario mimics a typical trend in many other parts of Cameroon where access to potable water remains a serious concern. In cities like Dschang (Western Region), Yaounde (Centre Region) and Douala (Littoral Region), studies have revealed the presence of both human and animal waste with significant concentrations of pathogenic organisms in local streams that flow through these areas (Temgoua, 2012; Djuikom et al., 2009; Fantong et al., 2016). The national water authority, Cameroon Water Utilities Corporation (CAMWATER) lacks the capacity to adequately supply potable water to the population especially during the dry season when surface waters have low charge (Roy, 2013). Hence, many people resort to wells, springs and streams for their daily water consumption – most of which are contaminated from sedimentation, sewage contamination, and agrochemical contamination. The problem is also compounded by direct fecal deposition, indiscriminate disposal of municipal refuse and the lack of any viable waste recycling system. A Cameroon government environmental and water review reveals that in the major cities, there is almost a non-existent collective sanitation system and inadequate waste treatment facilities (controlled landfills, wastewater treatment plants). Furthermore, almost all the old wastewater treatment plants are abandoned while effluents are being discharged from the hospitals and other industries by direct spilling onto urban lots and rivers (PANGIRE, 2009). These lead to the growth and proliferation of enteric bacteria, eutrophication and toxic algae blooms hence rendering the water unfit for direct human contact and other modes of consumption (Biradar et al., 2014).

In recent years following recurrent eruptions and other tectonic activities, there have been complaints of human contamination through direct consumption of the headwaters up the slopes of Mount Cameroon around Buea subdivision. With a basement substratum consisting of easily alterable MAFIC rocks and andosol favored by a very warm humid climate, intense mineralization and leaching occur (Ako et al., 2012). Hence the potential of metal dissolution into these surface waters needs to be investigated. The area falls within the Cameroon Hot Line (CVL) with crater lakes containing high concentrations of toxic magmatic gases under pressure. The occasional releases of these gases in recent decades have caused public health concerns.

There have been multiple studies conducted on the hydrogeochemistry of Mount Cameroon's water resources - springs and groundwater (Djieto et al., 2017; Ako et al., 2012; Akoachere and Ngwesse, 2017; Orock, 2006; Lambi and Kometa, 2009), a host of which have dwelt on water quality issues (Endeley et al., 2001; Riotte et al. 2003; Benedetti et al., 2003; Azah, 2009; Sorlini et al., 2013; Wotchoko et al., 2016; Lactem, 2016). Hence despite representing the most likely pathway for water-borne diseases onto riverine communities, the water quality of major water bodies (streams, lakes and rivers) on the flank of Mount Cameroon has not been studied holistically.

3 INTRODUCTION TO STUDY AREA

Cameroon, contemporarily called 'Africa in miniature', is indisputably one of the most beautiful countries in the world in terms of nature, culture and biodiversity though its politics are less pretty (White, 2004). These natural endowments assure the country an amazing agricultural potential, making it agronomically self-sufficient and hence an indispensable breadbasket to its neighbors - thanks to rich volcanic subsoil emanating from the Cameroon Volcanic Hot Line (CVL) (Lee et al., 1994).

The region around the flanks of Mount Cameroon constitutes a dense drainage network. With very fertile soils, the area displays a vivid depiction of the country's agronomic potentials with a dense population and intense agro-industrial concentration. The availability of reliable and substantial water resources and the fertility of volcanic soils have brought since ancient times, the intense settlement and agricultural exploitation of the lower flanks of volcanoes (Aiuppa et al., 2003). Mount Cameroon is a 4095 m high and 50 km wide volcano located on the Cameroon coast, in West Africa. It is an active volcano that has perpetually witnessed eruptions and lava flows as recent as in 1909, 1922, 1954, 1959, 1982, 1999 and 2000 (Riotte et al., 2002), 2005 and 2012. Accompanied by the creation of many fumaroles and geysers, solfataras and mudpots, it is one of Africa's most volcanically active peaks within the last century (Pamo, 2008). Cameroon is thus one of the countries in sub-Saharan Africa endowed with abundant water resources (UNDP, 2000). However, the distribution of Cameroon's water resources is not even as a result of variations in the relief, vegetative covers rainfall pattern and climatic changes **(**MINMEE, 1997**).** The area under study spans two administrative divisions in the South West Region of Cameroon.

The area of study was chosen as it constitutes the major townships along the immediate eastern flank of the Mount Cameroon massive (Figure 7). The area which is the most densely populated in the South West Region, falls between Latitudes 4° 5' 58"N - 4° 39' 24 7"N and Longitudes 9° 18' 29"E - 9° 33' 03"E and forms one of the most important ecological, geomorphological and socio-economic zones of Cameroon.

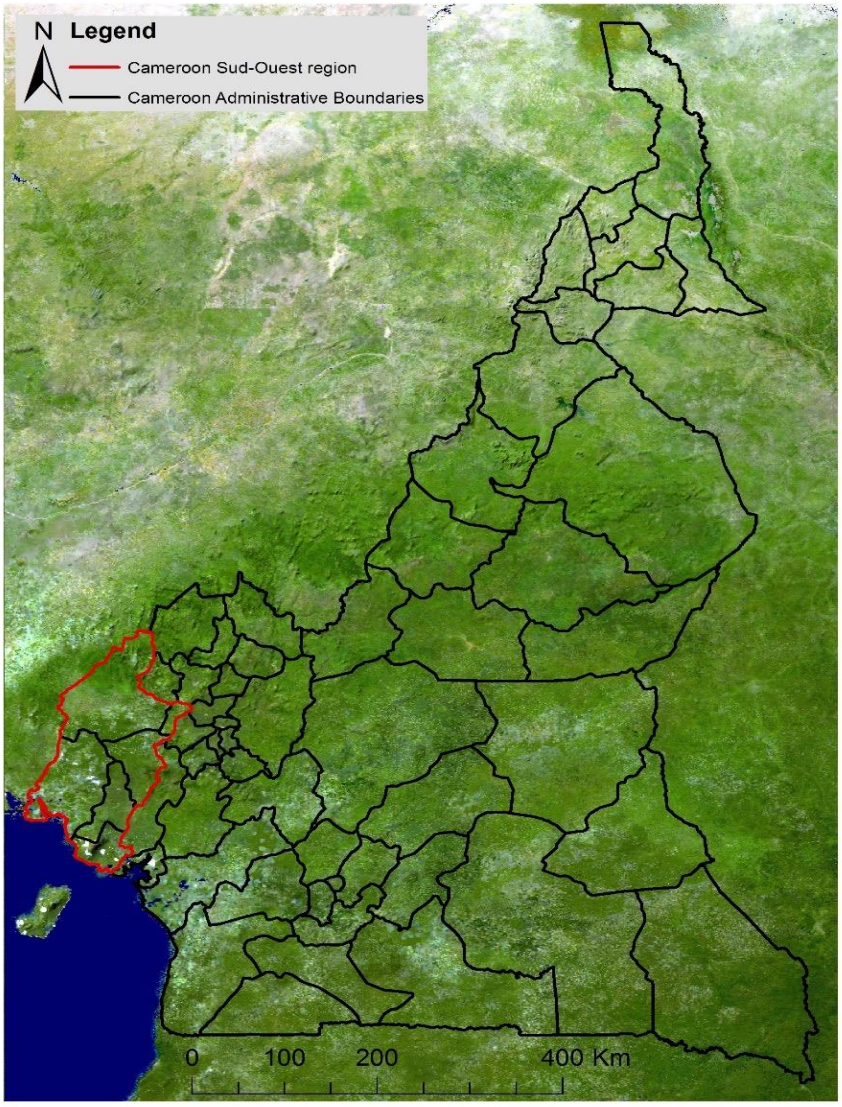

Figure 6. Map of Cameroon showing the province of the study area (Source: Diva-GIS.org, 2018)

3.1 Description of the Bio-physical Environment

3.1.1 Climate

The climate of the area under study is of the typical equatorial humid climate with the temperature ranging from as low as 20°C in the rainy season and as high as 33°C in the dry season. The rainfall increases to more than 10,000 mm a year with August representing the wettest month with an average monthly rainfall of 500 mm while January represents the peak of the dry season with mean precipitation as low as 30 mm. The rainfall decreases northwards from the coast. Humidity

is high with the mean annual relative humidity ranging between 80% and 95% in some areas (UCCC, 2014).

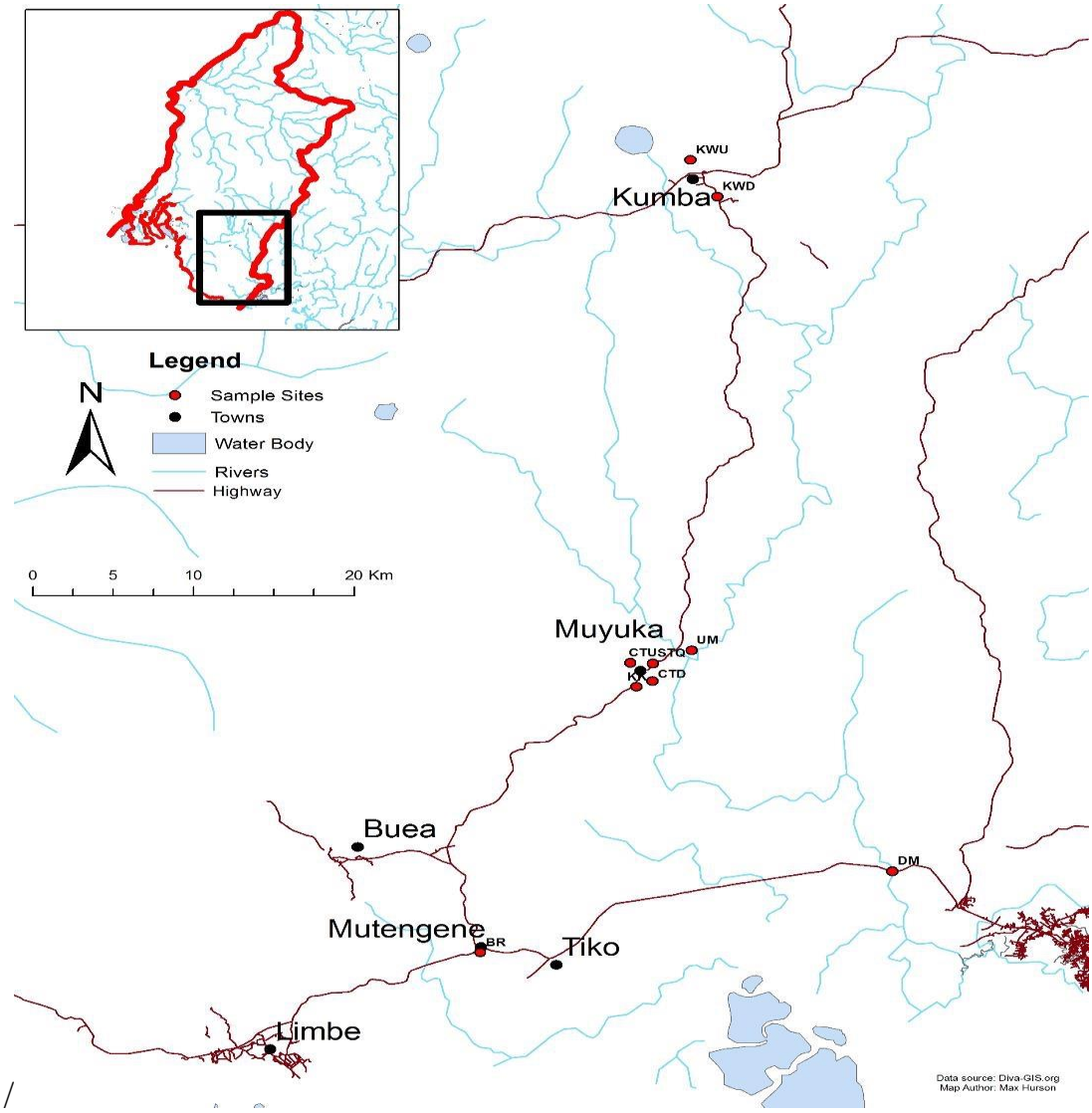

Figure 7. Map of study area showing sampling locations in letters (Source: Diva-GIS.org, 2018)

3.1.2 Petrology and Soil Type

Earliest record of volcanic activities on the Mount Cameroon area started during the upper Miocene age (11Ma ago), meanwhile the majority of sediments are dated from the Cretaceous to Quaternary (Duruelle, 1978). The area is characterized by a petrology reminiscent of the type of a Strombo-Hawaian volcanic phenomena which leads to the release of associated lava types

composed of ferromagnesian (MAFIC) basaltic lava (Chauvel et al., 2004; Benedette et al., 2003). The rock types produced are scoriaceous pebbles and gravels ranging from laterites, hawaites, picrites, tephra to tachybasalts (Duruelle et al., 1987). This mostly constitutes the underlying bed-rock which readily alters under the prevailing favourable humid conditions, into dark coloured andosols (Ako, 2016) blended with patches of alluvial and sandy loam (UCCC, 2014). The north-ern fringes where the town of Kumba is located contain lateritic subsoil mixed in with clay, brick red gravels and pale yellow to earthly sandstones. Through leaching and surface runoff during rainfall, these soil types impart a reddish coloration to the surface waters.

3.1.3 Relief

The relief of the area under study presents a non-uniformly undulated landscape characterized by U-shaped valleys, escarpments and steep hills (Wotchoko et al., 2016). Towards the coastal areas the topography gradually transforms into gently undulating lowlands and rolling hills interspersed with wetlands and flood zones (UCCC, 2014). Around the entire massive and throughout the flanks and axial section of the mountain, there exist more than 100 fissure-controlled cinder cones all extending towards the lowland areas (Ako, 2016).

3.2 Socio-Economic Drivers of Urban Pollution

This section will dwell on the investigative findings conducted on the field in the various major towns with the goal to highlight specific activities that serve as pollution drivers in the different local communities. In order to achieve a better idea of the sources of pollution it is important to review the various socio-economic activities in these urban areas through which the major rivers flow. Hence, during the course of this work, an investigation and outreach was carried out at the various municipalities in order to appraise some of the activities responsible for contamination of these water bodies.

A qualitative research was carried out in the city of Kumba, and the towns of Muyuka and Muten-gene. During these investigations, members of the local governments, city councillors, businesses and the local inhabitants were interviewed. With a population of above 400,000 inhabitants (World Gazetteer, 2013), the town of Kumba (latitudes: 4°36’’- 4°40’’, longitudes: 9°23’’- 9°29’’), is the most populated within the study area and the economic capital of the South West Region. The

climate is typically hot and humid with a short dry season of about 4 months (December to March) meanwhile the rainy season extends much longer (April to November). The average annual temperature is 27ºC with a corresponding annual rainfall ranging from 2298 mm to 3400 mm (OITC, 2012).

Certain activities were identified as major causes of pollution around the Kumba Urban Council area. Due to the inexistence of waste treatment facilities and collection system, the indiscriminate dumping of municipal solid and liquid wastes both directly unto the Kumba Water River and along the river valleys, presents a major challenge with respect to environmental pollution. Another source of pollution is the dumping of both liquid and solid hospital wastes which are released into the Kumba Water with little or no treatment. This is not only compounded by the existence of shallow pit toilets constructed on the river valleys by the greater part of the population without water cistern flushing lavatories, but also the abusive deposition of both decomposed animal (carcasses) remains and fecal excrements. The presence of many medium size industries and businesses ranging from palm oil production, woodworks, paints and alloys, open motor repairs workshops to various local artisanal centers, are all accompanied no proper waste management strategies. The result is the release of heavy oils and other organic pollutants on to the land. These compounds leach during rainfall and are transported into the river.

Figure 8. Wanton disposal of assorted chemical and solid wastes at the Fiango neighbourhood, Kumba, Cameroon, 2008.

The second most populated town within the study area is Muyuka (4° 17' 23"N - 9° 24' 44"E) with a population of about 120,000 inhabitants. While most of the municipal drivers of pollution are similar with Kumba, the Muyuka area is characterized by the rubber plantations from the Cameroon Development Corporation (CDC). The major source of pollution comes from the dumping of both solid and liquid decomposed wastes from the procession of natural rubber for exportation. The CDC is a parastatal company - an agro-industrial entity that grows processes and exports tropical crops such as bananas, semi-finished rubber, palm oil and palm kernel oil (CDC, 2014).

Figure 9. Upstream Mungo River at Penda-Mboko, Littoral, Cameroon, 2017

Figure 10. Downstream Mungo River, 2017

Due to the heavy agro-industrial activities around the area accompanied by non-existent and in some cases, ineffective waste disposal methods, there is potential release a lot of nutrients and other organic contaminants onto the Mungo River and Coast Timber stream which flow through the Muyuka area. Meanwhile in the Mutengene area, the deposition of animal carcasses and associated wastes from one of the major slaughter houses in the South West Province, directly into the Benyo Stream, remains a major source of concern.

4 MATERIALS AND METHODS

4.1 Desk Study

This consists of a thorough literature review including the use of secondary data, field investigation and interviews with local authorities and the public, and a study of the topographic map of the study area. The reason for the field investigation and interview was to assess the socio-economic drivers of surface water contamination (as described in Chapter Three) in order to decide which water bodies were to be investigated. A topographic sheet of 1:50,000 was extracted online to locate the regional jurisdiction encompassing the study area (Figure 6). Meanwhile another map showing the catchment area under study was developed from DIVA GIS and used to identify the different water bodies to be sampled within the study area as seen in Figure 7.

4.2 Field Work

4.2.1 Reconnaissance Survey

A field survey was carried out in the study area during the mid of August 2017 which was undertaken at the peak of the rainy season. The rationale behind choosing this period is because the water bodies contain the most dissolved matter due to increased erosion and run offs caused by persistent rainfall. 9 sampling stations were chosen from a total of 5 rivers and streams. Three of the six rivers and streams (Kumba Water, Coast Timber River Muyuka and the Mungo River) had sampling stations on the upstream section (entering the town) and at the downstream section (where the water body exists in the town). Meanwhile the remaining three streams were each assigned a single sample station. The logic behind choosing the sample points at both upstream and downstream levels was to account for potential changes in concentrations due to human activity. The Stone Quarters Stream (STQ) in Muyuka which was also sampled is a tributary of the Coast Timber River. This small stream which occasionally exhibits a characteristic pungent odour, has a very short course issuing from the ground around the eastern part of the town. It is extremely deficient in light and air (oxygen) for much of its course and flows through neighborhoods making it a ready dumping ground for diverse sources of domestic and industrial wastes. This followed a strategic review with the advice of Dr. Ako Andrew of the Ministry of Mines, Water and Energy, who factored in the intensity of socio-economic activities, population density and the length of

water body traversing the chosen settlements. This was necessary to enable an acquaintance and familiarity of the study area and to fulfill the objectives of the research.

4.2.2 Sampling and Laboratory Analyses

After the field survey was conducted, sample collection followed on August 19 – 20, 2017. For sample collection, this took place at the middle of the river where flow is highest, and the mixing is maximum. This is because of higher flow velocity allowing good homogenization of the dissolved matter and solid particles (Li et al., 2014; Ndam Ngoupayou et al., 2016). The samples were collected by immersion in the middle of the streams (sampling sites) using pre-cleaned, acid-cleansed polythene Supermont 2L bottles. Sampling on the river Mungo sampling site was taken with the help of a boat due the water size. Samples to be used for trace element determination were stored refrigerated at 4°C after filtration. Samples for the analysis of anions were stored unacidified.

The following parameters were analysed in situ on the field immediately after sampling: Electrical conductivity (µS/cm), water temperature (°C), pH, turbidity (NTU), dissolved oxygen (DO) (mg/l), and total dissolved solids (mg/l). In keeping with standard procedures, these physical parameters where measured on-site to avoid unpredictable changes in characteristics due to their unstable nature (APHA/AWWA, 1998). While the Hach portable turbidimeter Model 2100P was used to measure turbidity, the portable Hach HQ40D meter was used for the combined analyses of pH, dissolved oxygen (DO), total dissolved solids (TDS), and electrical conductivity (EC). In order to record the electrical conductivity, water temperature and pH values at the collection sites, the electrodes of the equipment were immersed in the water and left settled until the values in the monitoring screen became stabilized. In order to stabilize the pH meter, it was calibrated with pH 4.0 and 6.8 buffer solutions. The instruments were rinsed thoroughly with distilled water immediately after recording the readings at each sample point in order to avoid contamination from the sample.

Figure 11. Hach HQ40D meter for measurement of physico-chemical analyses

Total kjeldahl nitorgen (TKN), total phosphorus and alkalinity were all measured within 24 hours of collection at the "Institut de Recherche Agricole pour le Développement" (IRAD) at Ekona. For total kjeldahl nitrogen, the Kjeldahl digestion method was used. Samples were digested at 360–410°C with concentrated sulphuric acid (H_2SO_4) to release reduced nitrogen as ammonium sulphate. The end of the condenser was dipped into boric acidand the sample solution distilled with a small amount of sodium hydroxide (NaOH) being added with a dropping funnel. NaOH reduces the ammonium (NH_4^+) to ammonia (NH_3), which boils and bubbles through the standard acid solution and produces ammonium salts. Ammonium ion (amount of nitrogen) concentration in sample is measured via direct acid-base titration with HCl acid.

For total phosphorus measurement, the ascorbic acid procedure was employed (USEPA, 1978). The samples were filtered through a membrane filter (0.45-µm pore diameter) and 50 mL of samples were pipetted into a clean, dry test tube with the addition of 1 drop (0.05 mL) of phenolphthalein indicator and mixed. Drops of 2.5 M H_2SO_4 were added to eliminate development of reddish coloration. 8.0 mL of combined phosphate reagent was added and mixed thoroughly, after which samples were left to settle for about 20mins in order to determine their respective absorbance at

880 nm, using reagent blank as the reference solution. The reagent blank was 50 mL of distilled water which underwent same digestion steps and ascorbic acid procedure. The actual absorbance of each sample was determined by subtracting absorbance of the blank from the sample's measured absorbance. The respective measured absorbances were marked against the calibration curve in order to determine the concentration. Each set of samples included one P standard to guarantee accuracy of the results.

The analyses for alkalinity would be elaborated subsequently under water chemistry analyses.

Meanwhile the altitude and geographic location of the various sample sites were recorded in the field with the Garmin Vista CX Global Positioning System (GPS) and the coordinates obtained were used to obtain a cartographic representation of the study area through the use of ArcGIS version 9.3 software. This data was used as a reference material for the production of a geo-referenced location where samples were collected. During the sampling process, the water was collected from the sample site directly into 4 jars that were thoroughly rinsed, and also into four 500 ml capacity narrow neck plastic bottles that were also rinsed three times with the water in accordance with standard procedures (Leo Nollet, 2007; Rodier, 2009). Among the four sets of the 500 ml of water samples collected at each sample site, one bottle was for major cations (Na^+, K^+, Ca^{2+} and Mg^{2+}) where analyses were done with a drop of 0.5N nitric acid (HNO_3). The second set of bottles which contained no nitric acid were filled with water samples for major anions (Cl^-, SO_4^{2-} and NO_3^-) analyses, meanwhile the third set was filled with samples that were used for determining alkalinity (HCO_3^-) and the fourth set was used for microbial analyses.

All bottles containing samples collected from the sample points were cocked and stored in a coolant containing ice blocks to maintain a suitable temperature of 4ºC. In order to prevent contamination from the instruments, they were thoroughly rinsed by distilled water immediately after recording of the obtained values. The sample set destined for the analyses of major ions were transported to the Laboratoire de Géochimie des Eaux (LAGE) of the Institute of Geological and Mining Research (IRGM) at Nkolbisson, Yaounde for analyses.

Figure 12. Sampling and data recording of Benyo River, Mutengene, Cameroon

Figure 13. Institute of Geological and Mining Research (IRGM), Yaoundé, Cameroon

4.3 Microbial Analyses

The microbial analyses were conducted with a double goal: To determine the total bacteria count in the various water samples and also to separately determine their total coliform counts. It should be noted that total coliform level also constitutes part of the total bacteria count. The total bacteria count provides a quantitative idea about the presence of microorganisms such as bacteria, yeast and mold in a sample. In accordance with McGraw-Hill (2002), the total bacteria count generally reveals the level of contamination of drinking and recreational waters and represents the number of colonies forming units (cfu) per ml of a given sample. Meanwhile the total coliform count gives an indication of the level of disease-causing pathogens in a sample. Coliforms are gram-negative rod-shaped bacteria that are capable of fermenting lactose. However, not all coliforms are disease causing microbes. They provide a degree of fecal contamination due to their presence in the gastrointestinal tracts of humans and animals.

4.3.1 Analyses of total bacteria using Plate Count Agar Method

The medium contained pancreatic casein enzymatic hydrolysate, yeast extract, glucose and agar at a pH of 7. The casein which provides essential amino acids and the yeast extract which supplies vitamin B-complex provide a readily available source of nutrient for bacterial growth while the glucose serves as an energy source. Appropriate decimal dilutions in sterile diluent were prepared in order to obtain between 30-300 CFU per petri dishes containing individual samples. The molten agar surface was antiseptically inoculated with 0.1ml of the well mixed diluted sample. The dilution was evenly spread over the surface of the medium and the inoculum was evenly distributed over the agar surface with the help of a sterile spreader device. The petri dishes were rotated gently to ensure uniform mixing and aerobically incubated for 48 +/- 2.0 hours at 35ºC. The dishes were examined for bacterial growth after incubation and the number of colonies was counted in terms of colony forming units (CFU)/L per sample, with respect to the dilution factor. The precipitated zones of para-casein are indicated by whitish zones surrounding colonies, meanwhile the transparent zones indicate casein digestion by bacteria. Either reaction indicates the presence of caseolytic bacteria (Hardy Diagnostics, 2018).

4.3.2 Analyses of Total coliform using violet red bile (VRB) agar

The medium contained bile salts and crystal violet which served an inhibitory role against some gram-positive microbes like staphylococci while neutral red was used as a pH indicator. It was allowed to warm to room temperature prior to inoculation. In order to melt the bottled media, it was autoclaved at 121ºC for 1-3 minutes until melted. Decimal dilutions in sterile diluent were prepared in order to obtain between 30-300 CFU per petri dish meanwhile the agar surface was antiseptically inoculated with 0.1ml of the well mixed diluted sample. The dilution was evenly spread over the surface of the medium and the inoculum was rotated gently and distributed over the agar surface with the help of a sterile spreader device. Plates were aerobically incubated for 48 +/- 2.0 hours at 35ºC. The lactose-fermenting coliforms produced pink to red colonies that were being surrounded by a reddish zone of precipitated bile (Hardy Diagnostics, 2018).

4.4 Analysis of Water Chemistry

4.4.1 Measurement of Alkalinity

The measurement of alkalinity values for each sample was conducted within 24 hours after the sample was collected in order to prevent precipitation of mineral phases, oxidation of ferrous ions and sulphides. With the utilization of standard titration procedures by an 862 Compact Metrohm model (Fantong et al., 2009), the measurement of alkalinity was performed four times for each sample and the mean value was considered for the alkalinity. The following equation was used to calculate the HCO_3^- concentration for each sample from the titration parameters:

HCO_3^- (meq/l) = Total dissolved solids x 61/1000…… (2)

Where 61 is the molar mass of bicarbonate.

4.4.2 Analysis for Major Ions

Laboratory analyses for major cations (Na^+, K^+, Ca^{2+}, NH_4^+ and Mg^{2+}) were conducted in late August 2017. These were determined with a non-suppressed ion chromatography (DIONEX, ICS-900) while the major anions (F^-, Cl^-, SO_4^{2-}, NO_3^-, PO_4^{3-}, HCO_3^-) were analyzed with a suppressed ion chromatography (DIONEX, ICS-1100). The Dionex ICS-1100 consists of an integrated ion chromatography system with a pump, injection valve, and a conductivity detector. It is configured with a high-pressure valve for sample preparation and a standard bore (4mm) and microbore (2mm) column heater for temperature control. It uses a RFIC-ER (Reagent-Free Ion Chromatography with Eluent Regeneration) method that is being remotely controlled by a personal computer. Figure 14 gives an illustration of the different six stages of a typical IC S – 1100 analyses.

1**. Eluent Delivery**

The liquid sample being an isocratic delivery system means that the eluent composition and concentration remain constant throughout the run.

2. Sample Injection

The liquid sample is injected into the eluent stream and pumped through the guard and separator columns (chemically-inert tubes packed with a polymeric resin), with the removal of contaminants that might poison the separator column.

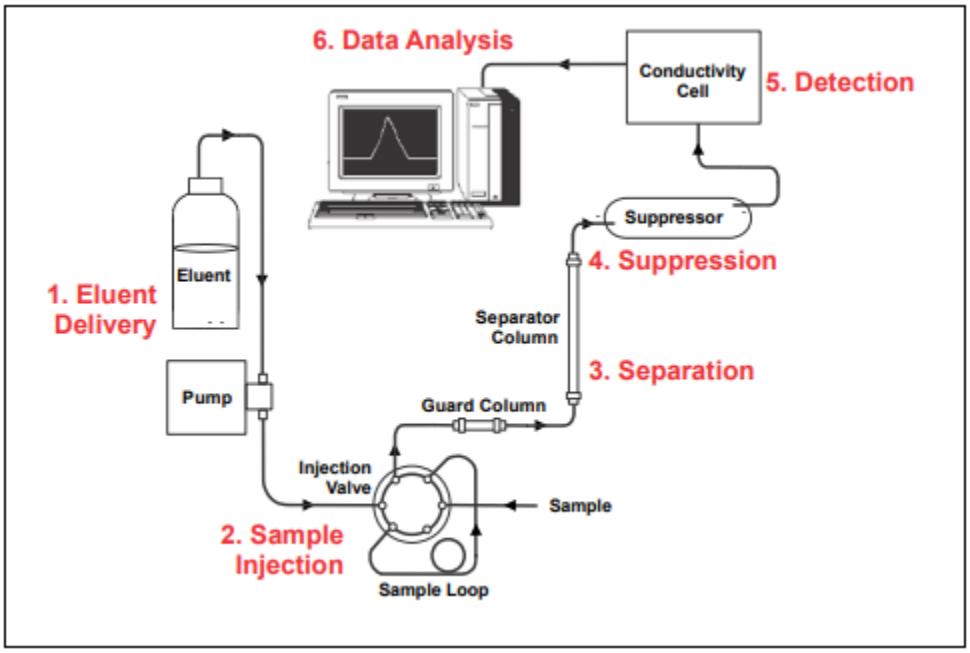

Figure 14. A typical Dionex ICS-1100 Ion Chromatography System. (Source: Thermo Scientific, 2012)

3. Separation

The sample ions are separated as they migrate through the IC column at different rates, contingent upon their interactions with the ion exchange sites.

4. Suppression

The sample ions exit the column and flow through a suppressor that suppresses the eluent conductivity while selectively enhances detection of the sample ions.

5. Detection

The electrical conductivity of the sample ions is measured by a conductivity cell while exiting the suppressor. Depending on the physico-chemical properties of analytes, a signal is being produced.

6. Data Analysis

A conductivity cell transmits ion signals to a data collection system, which are then identified in accordance with their retention times. The results are displayed as a chromatogram (integrating the peak area or peak height) and the concentrations of ionic analytes are registered.

For the cation analyses, samples were immediately acidified to a pH < 2 through the addition of nitric acid. Meanwhile for anion analyses, the samples were collected into 250ml bottles without preservation. Dilution and filtration pretreatments were carried out before samples were introduced into the IC. And all samples were filtered using a 0.2 μm cellulose filter in order to avoid the blockage of the IC analytical column. Before the analyses could be performed, samples with electrical conductivity (EC) values above 200 (between100-199), were diluted by 10, and 5, times and less than 100 were not diluted, respectively. Such sample dilution is necessary when the electrical conductivity (EC) exceeds the working capacity of the chosen column as well as to maximize sample matrix effect. This was a precautionary procedure served to avoid the column of the IC from being over worked. Procedural blanks and reagents were prepared and determined in parallel to the sample treatments using identical procedures (Lactem, 2016; Rakotondrabe et al., 2018). Meanwhile ultrapure water (MQ) of 18.2 MΩ·cm resistivity was applied for all analyses as well the blanks with each calibration curve analyzed from quality control standards before, during and after analyzing a set of samples. Results of the chemical analyses were only accepted within a charge balance error range of ±5% (Rakotondrabe et al., 2018).

Verification of the reliability of chemical measurements was achieved using the Charge Balance Equation (Dominico and Schwartz, 1990). It should be noted that the basic characteristic of water

is that the sum of the positive and negative charges for all containing dissolved species should be either close to or equal to zero in keeping with the principle of electrical neutrality (Younger, 1994; Deutsch, 1997; Weight and Sonderegger, 2001). Hence, all the acquired laboratory data were calculated and evaluated in order to ascertain if the measured concentrations provided an electrically neutral solution (Deutsch, 1997). This was achieved through conversion of the measured concentration in mg/l (ppm) to milli-equivalent unit for each major ionic species as follows:

Meq/l = mg/l/Atomic number x charge

$$\mathbf{CB = (\sum cations\ (meq/l) - \sum anions\ (meq/l)/\sum cations\ (meq/l) + \sum anions\ (meq/l)) \times 100} \quad \mathbf{(3)}$$

The charge balance in percentage (CB) for reliability of chemical measurements was calculated after Domenico and Schwartz (1990) as shown in equation 3. The results showed that ion balance for the samples had values within an acceptable range of ±5 %. For result presentation, the water courses (samples) were assigned letters against the data collected in a tabular format with each group of letters representing a particular sample. Presentation of results is in tables, plots, graphs, charts and maps where appropriate.

4.4.3 Analyses of Trace Elements

Laboratory analyses for heavy metals were conducted at the Environmental Engineering laboratory, Concordia University. The 9 samples to be analyzed were preserved in 250 ml narrow neck plastic bottles with the addition 1% HNO_3+0.5% acid mixture. The bottles were tightly sealed and shipped to Concordia University for analyses. The essential trace metals were determined through the use of Inductively Coupled Argon Plasma Mass Spectroscopy (ICP-MS Agilent 7700X Series). Each sample was further diluted twice with an acid mixture composed of HNO_3 and HCl (ICP-MS grade), in order to bring elemental concentrations below 100 ppb concentration detection limit. The acid mixture was produced by the use of ultra-pure water. In order to remove suspended solids from the samples, they were passed through a 0.2 μm filter size syringe filter. The ICP-MS enables the determination of trace elements up to the range of parts per trillion.

The elements simultaneously analyzed were As, Al, Cd, Cr, Pb, Sr, Mn, Fe, Cu, Co, Ni, Zn and Ba. The samples were determined in accordance with their weight over charge ratio after being

ionized through high temperature argon plasma. The samples were then digested with different reagents (concentrated HNO_3, concentrated HCl, 30% H_2O, deionized water) according to 3050B EPA Method, filtered through a 0.2 µm filter and further diluted to ensure elemental concentration ranges between 1 to 100 ppb (µg/L). In order to obtain the various elemental concentrations, the samples were further acidified with the help of high purity trace metal acids (1% nitric acid and 5% hydrochloric acid).

4.5 Data compilation and statistical methods used

Multivariate Statistical Analyses (MSA) was used to process data collected under standard hydro-chemical methods with the utilization of the software, Rockwock15 supplied by Rock Ware. The analyses generally correspond to the various statistical methods that can be employed in order to simultaneously analyze two or multiple geochemical variables simultaneously. They are linear stoichiometric plots of major ions applied to group water samples and to identify the main factors and sources of contamination (Kim et al., 2003). The analyses help to separate samples into hydrogeochemical facies which represent groups that show similar characteristics. Not only do these similar hydrochemical characteristics provide clues into the physico-chemical processes occurring in these water bodies, they also provide an understanding of the nature of the bedrock over which they flow or of the aquifer from which they issue as springs (Guler et al., 2002). The allocation of resources towards a sustainable and proper management of surface waters like springs and rivers can be achieved through proper understanding of the hydrochemistry and the factors that influence their chemical compositions (Ako, 2012). They can be classified and represented with respect to the dominant ions in the various facies by means of several stoichiometric plots. In this study the various plots used to describe the water samples were Piper Plots, Stiff pattern diagram, Box and Whisker plots, Dendograms and Principal Component Analyses. The piper‘s trilinear and the Stiff diagrams in particular as elaborated by Wotany et al. (2013) and Fantong et al. (2009), were used to determine water types, degree of mineralization and the spatial evolution and variation in the chemistry of the observed water bodies.

4.5.1 The Piper Plot

This is a trilinear diagram commonly used in hydrochemical studies and used in portraying a graphical representation of water samples (Piper, 1944). The various major ions (anions and

cations) are represented by separate ternary plots whose axes represents 100% concentration of each three constituents. The ternary plots culminate into a diamond shaped matrix in between representing water composition (Rao, 1998). The whole plot consists of two triangular fields and an intervening diamond-shaped field above, all having scales of 0-100% of the total equivalents per million corresponding to axis of hydrogeochemical facies (Appelo and Postma, 2005). The cationic apices are represented by sodium and potassium ($Na^+ + K^+$), magnesium (Mg^{2+}) and calcium (Ca^{2+}). Meanwhile the anionic apexes are represented by carbonate and hydrogen carbonate ions ($CO_3^{2-} + HCO_3^-$), chloride (Cl^-) and sulphate (SO_4^{2+}).

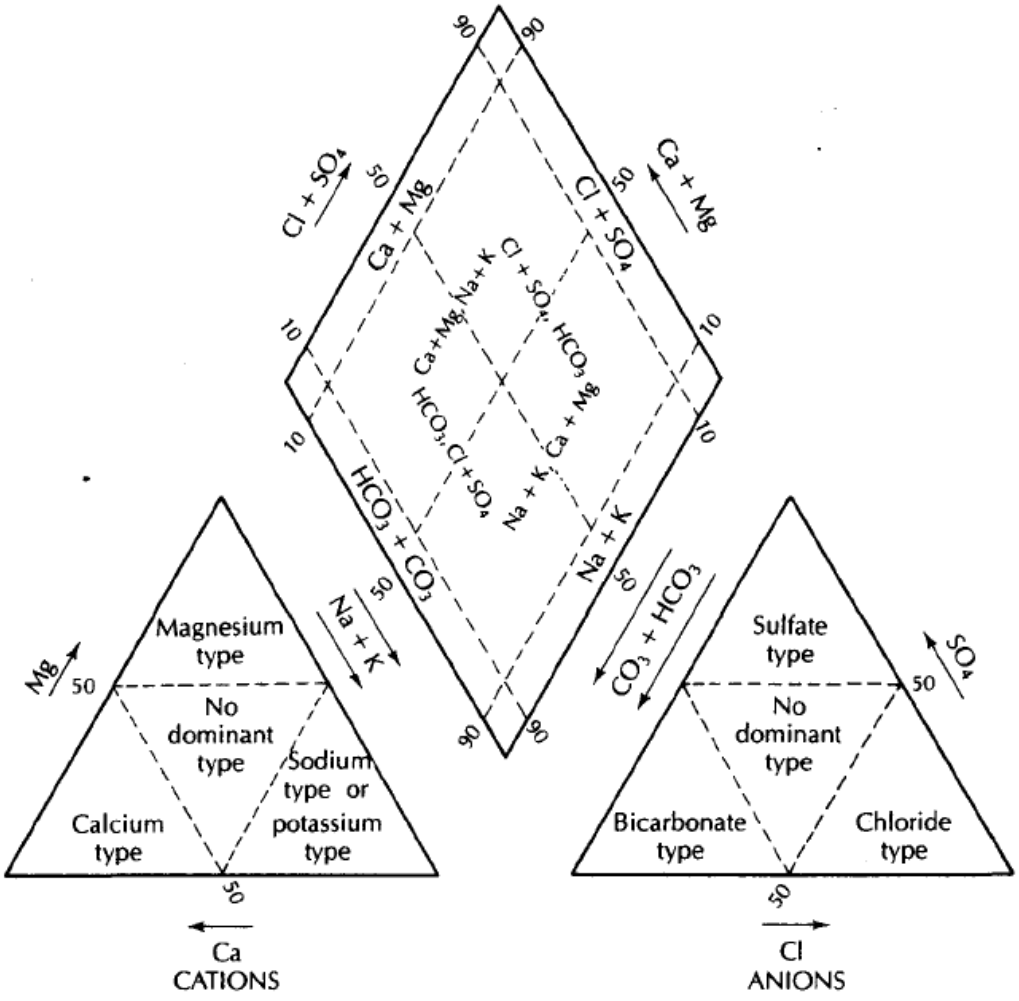

Figure 15. Hydrochemical classification system for natural water using Piper trilinear diagram (Fetter, 1988)

The trilinear diagrams (Figure 15) reveal both similarities and dissimilarities among water types as samples with similar characteristics tend to converge as a group. The Piper diagram has been used by several authors in hydrochemical analysis to characterize groundwater types (Rako-tondrabe et al., 2018; Fantong et al., 2009; Jiang et al., 2009).

4.5.2 The Stiff Diagram

Another diagram used to graphically represent the hydrochemistry of water samples is the Stiff diagram or Stiff pattern (Stiff, 1951). They portray mineralization and chemical composition within a catchment area. Stiff diagrams plot milliequivalent concentrations of cations on the left of the zero axes while the anions are plotted to the right. Each ion is plotted as a point, and the points are connected to form a polygonal shape. The ions are plotted each as a point which connects forming a polygonal shape in a consistent order Na+K across from Cl; Ca across from HCO_3^+, CO_3, Mg across from SO_4^{2-} forming polygons that becomes that sample's "signature" (Rockwork, 2018). The more extended the polygonal shape, the greater the concentration of the ions. Hence the Stiff patterns are useful markers in making an inference of water samples with diverse origins (Figure 16).

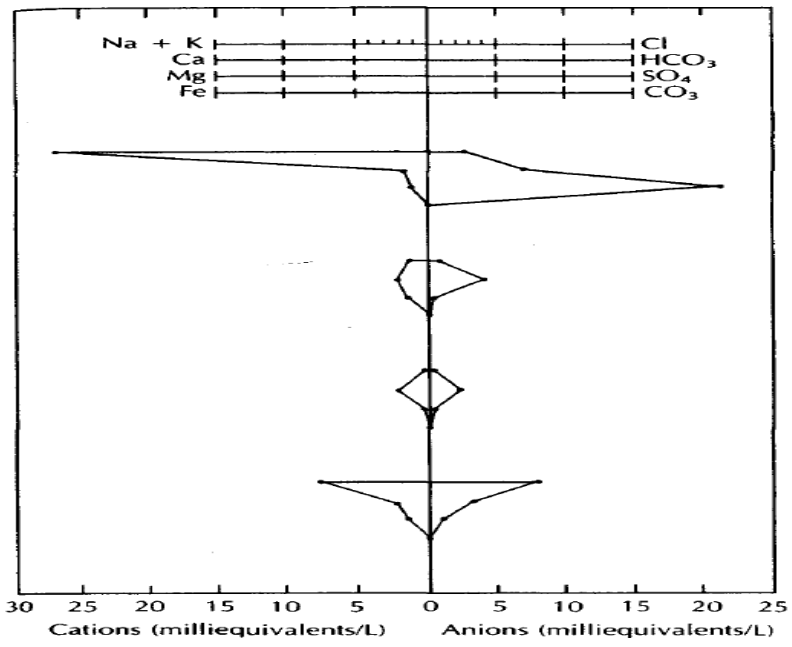

Figure16. A typical Stiff diagram. (Source: Hem, 1985)

4.5.3 Box and Whisker

These are graphical depiction of groups of numerical data using quartiles with vertical extensions outside upper and lower quartiles (Affum et al., 2015). Also called a boxplot, it presents information from a five-number summary and especially useful for indicating whether a distribution is skewed and if there are potential unusual observations (outliers) within a given data set. They are also useful for numerous observations and for comparing two or multiple data sets. It shows the shape of the distribution, the central value, and variability of a given data set (Statistics Canada, 2017).

In a box and whisker plot:

- The box's edges are the upper and lower quartiles/percentiles, spanning the interquartile range
- The median depicts the vertical line inside the box
- The whiskers represent the two lines outside the box that extend to the maximum and lowest observations (Statistics Canada, 2017).

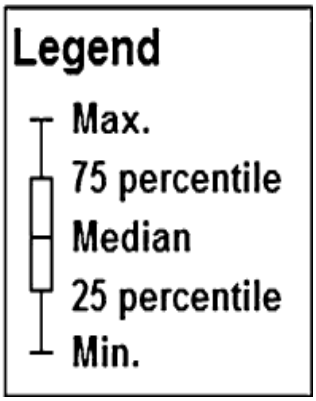

Figure 17. Legend showing different sections of a typical Box plot (Source: Hem, 1985)

4.5.4 Dendogram or Hierarchical Cluster Analysis (HCA)

Hierarchical Cluster Analysis (HCA) was also used to analyze the different ions. These are tree structured graphs that hierarchically clusters species into increasingly more inclusive groups depicting similarity or dissimilarity between species by rows and columns depending on selected

distance measure (Affum et al., 2015). They are commonly used data classification techniques in which objects are grouped into the same category such that their similarity can be used to construct a dendogram (Davis, 1986; Cloutier et al., 2008; Güler et al., 2012; Moya et al., 2015).

The dendograms help identify the relationships or closeness of hydrochemical parameters through the inter-variable similarities as similar objects converge into the same class (Rakotondrabe et al, 2018). The Q-mode dendogram represents a regrouping of all water samples in terms of water quality. Meanwhile the R-mode cluster represents regrouping of the various hydrochemical parameters and how they inter-relate. Hence, they can be derived as R-mode representing hydrochemical parameters and Q-mode representing water samples (Ayenew et al., 2009; Affum et al., 2015).

The usefulness of HCA is the ability to provide a classification for water samples and their respective geochemistry into distinct clusters and/or sub-clusters whose distinction may give a clue to influential contamination factors like anthropogenic activity, residence time, the type of aquifer through which groundwater flows or the substratum beneath the flow of surface water. This can help in understanding the evolution of the different cluster groups and subgroups, and in conducting hydrogeochemical modeling (Ayenew et al., 2009).

4.5.5 Principal component analysis

Principal Component Analysis (PCA) is widely used in hydrogeochemical analyses to identify the most dominant factors/components within a data set (Helena et al., 2000; Farnham et al., 2003; Kamtchueng et al., 2016; Rakotondrabe et al., 2018). It determines the contribution and influence of species in relation to their percentage variance to a given data set (Afum et al., 2015) and helps profile the correlation between parameters (Sorlini et al., 2013). The set of variables (principal components) are derived from linear combinations and classified such that the dominant components (usually two or three) control most of the variation in the data set (Everitt and Hothorn, 2011; Matiatos et al., 2014; Ogwueleka, 2015; Ravikumar and Somashekar, 2017).

4.6 Health Risk Assessments

4.6.1 Exposure Assessment

In this study the exposure assessments of certain trace elements were analyzed in order to assess potential toxicity to the local inhabitants who are exposed to these surface water systems for different purposes ranging from direct ingestion through swimming, cooking and laundry, and for other domestic household chores. According to the USEPA (2017), exposure assessment deals with the processes occurring at the interface between an environmental contaminant and a target organism. These processes are usually facilitated by contact of a contaminant with physically visible external boundaries which can be the mouth, nostrils and skin (U.S. EPA, 1992a). Quantitatively, the goal of exposure assessment is to deduce the concentration, form and rate at which an adverse biological effect can occur through the result of uptake by an organism. It is the process by which:

1 - Populations at risk are identified;

2 - The conditions of exposure and the potential pathways are identified;

3 – And the potential doses are quantified.

In this study the exposure assessment applications is based on human health though it can be applied to other organisms within the ecosystem. There are three pathways through which contaminants can get into the human body: dermal absorption, respiratory and oral routes (USEPA, 1992). The oral route as seen in Figure 18 remains the most predominant for elemental ingestion into the human body and constitutes the most common basis for health risk assessment models (USEPA, 1998). Hence health exposure assessments were conducted for selected trace elements whose concentrations registered unusually high values in one or more samples, among which are aluminum, iron, manganese, and cadmium. The Average Daily Intake (ADD) and Pollution Index (PI) were deduced from the above-mentioned elements in order to ascertain the health risk of the concerned population over time.

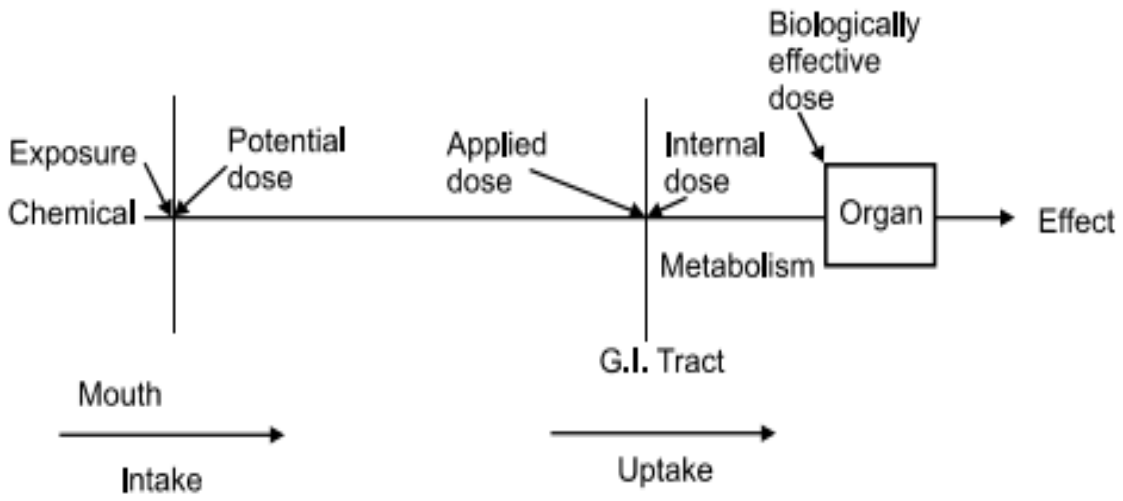

Figure 18. Schematic representation of oral exposure to contaminant (Source: EPA, 1992)

4.6.2 Heavy Metal Pollution Index (HPI)

Heavy Metal Pollution Index (HPI) is a rating technique that provides the composite influence of each trace metal on the overall quality of water (Majhi and Biswal, 2016). It was computed to evaluate overall pollution of water with respect to all containing trace metals in each sample. The pollution index was used in this study to evaluate the degree of trace metal contamination (Emoyan *et al.,* 2005; Nier 2007; Rakotondrabe et al., 2018). The formula used in this study is derived from the USEPA (2007) drinking water standards where the tolerable levels were used to obtain the Pollution Index (PI). The tolerable level is considered as the concentration in water suitable for human ingestion for which 100 is the critical value (Lee at al., 1998). Hence HPI<100 indicates low trace metal pollution, HPI = 100 indicates threshold for risk, and HPI>100 indicates heavy metal pollution (critical pollution index).

The HPI is derived from the following formula:

$$HPI = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i}, \quad \text{..... (4)}$$

Where: Wi= the unit weightage of the ith parameter,

Qi= the sub-index of the ith parameter,

n= the number of parameters considered,

$$Q_i = \sum_{i=1}^{n} \frac{\{M_i(-)I_i\}}{(S_i - I_i)} \times 100, \quad \text{..... (5)}$$

Where Si= the standard value of the ith parameter.

Mi= the monitored value of heavy metal of ith parameter,

Ii= the ideal value of the ith parameter,

The (−) sign represents a numerical difference of the two values.

The criteria for choosing the Pollution Index of the respective sites in this study was contingent upon the trace metal concentration of the corresponding samples. The samples showing extraordinarily high trace metal concentrations were used as a benchmark to calculate pollution indices. The PIs of trace metals including Al, Fe, Mn and Cd were all calculated with respect to their highest and lowest concentrations in different samples.

4.6.3 The Average Daily Dose (ADD)

The average daily dose (ADD) of a contaminant is one of the most important metrics used in toxicity to express exposure assessments. The ADD is applicable for exposure for chemicals with non-carcinogenic and non-chronic effects. It is the average dose rate over a specific period of exposure expressed as daily dose per unit body mass (mg/kg/day). It can be derived through the following formula (USEPA, 2003).

ADD = C x IR x ED x EF/BW

Where: C = Concentration in water (μg/L)

IR = Ingestion rate (2L/person/day)

ED = Exposure duration (assumed 67 years)

EF = Exposure Frequency (unitless)

BW = Adult body weight (72 kg)

ADD = Average Daily Dose (mg/L/day)

In accordance with the Pollution Index, the average daily doses were calculated for key metals (Al, Fe, Mn, Cd) whose concentrations were unusually high in one or more samples.

5 RESULTS AND DISCUSSION

This chapter deals with the presentation of the results derived from both field and laboratory analyses including microbial analyses to physico-chemical parameters. The results of the analyses for all samples are presented in figures, tables and histograms. The parameters analysed were pH, conductivity (EC), alkalinity, temperature, turbidity, dissolved oxygen (DO), total dissolved solids (TDS) which are all represented in Table 2. Results obtained from the laboratory include major ions presented in Table 6, Figures 29 and 30; trace elements in Table 7 and total bacteria and coliforms counts in Table 3.

5.1 Physico-chemical Parameters

As seen from Table 2, the pH values for all samples range from 6.9 recorded at Stone Quarters Stream to 8.28 at Benyo River. These values were inversely proportional to that of dissolved oxygen with the least concentration at STQ and the most at BR. The STQ sample is slightly acidic and falls below the WHO (2004) range of pH 6.5 – 8.5. While water samples of both DM and KWD reveal highest turbidity values, samples from the Coast Timber and Kwekwe Rivers that run through Muyuka Township, had the least turbidity values. Meanwhile the electrical conductivity was highest at Kwekwe River followed by STQ and Benyo River, while the least values were from all Kumba water and Mungo River samples. These values were largely consistent with the resultant values for total dissolved solids (TDS) and alkalinity albeit with downstream Mungo having an exception to the trend. The concentration of total dissolved solids was highest in KK, STQ and BR in that order while the all Mungo River and Kumba Water and STQ samples had higher values for suspended solids and turbidities.

Table 2. Representation of Physico-chemical Parameters

	Alti-tude (m)	Latitude	Longi-tude	Tempera-ture (^{0}C)	Dis-solved Oxygen (mg/L)	Conductiv-ity (S/m)	Total Dis-solved Solids (TDS)	Alkalin-ity (meq/L)	Turbid-ity (NTU)	pH
KWU	251	N04º 38’ 70”	E009º26’ 04”	24.8	7.8	29.8	14	46	27.8	7.38
KWD	212	N04º 14’ 83”	E009º 26’ 95”	24.8	7.5	38.8	18.2	68	52.4	7.18
UM	32	N04º 29’55”	E009º 43’94”	25.5	7.9	41.2	19.3	209	20.4	7.33
DM	10	N04º 29’ 55”	E009º 14’83”	26	7.8	55.7	26.2	393	40	7.29
CTU	48	N04º 29’15”	E009º 40’17”	25.1	8.2	177.6	84.3	359	7.2	7.63
CTD	2	N04º 27’ 72”	E009 º 47’ 55”	26	8.44	184	87.3	317	9.63	7.90
KK	33	N04º 27’82”	E009º40’ 48”	25	8.3	305.3	146.2	635	4.6	7.96
BR	143	N04º 08’ 17”	E009º 31’46”	24.1	8.7	218.7	103	352	16.7	8.28
STQ	36	N04º28’ 36”	E009º 41’98”	26.3	2.2	236.7	112.8	271	24.1	6.90

5.2 Microbial Analyses

The results of microbial analyses as seen from Table 3 revealed that all water samples are unfit for incidental ingestion or drinking.

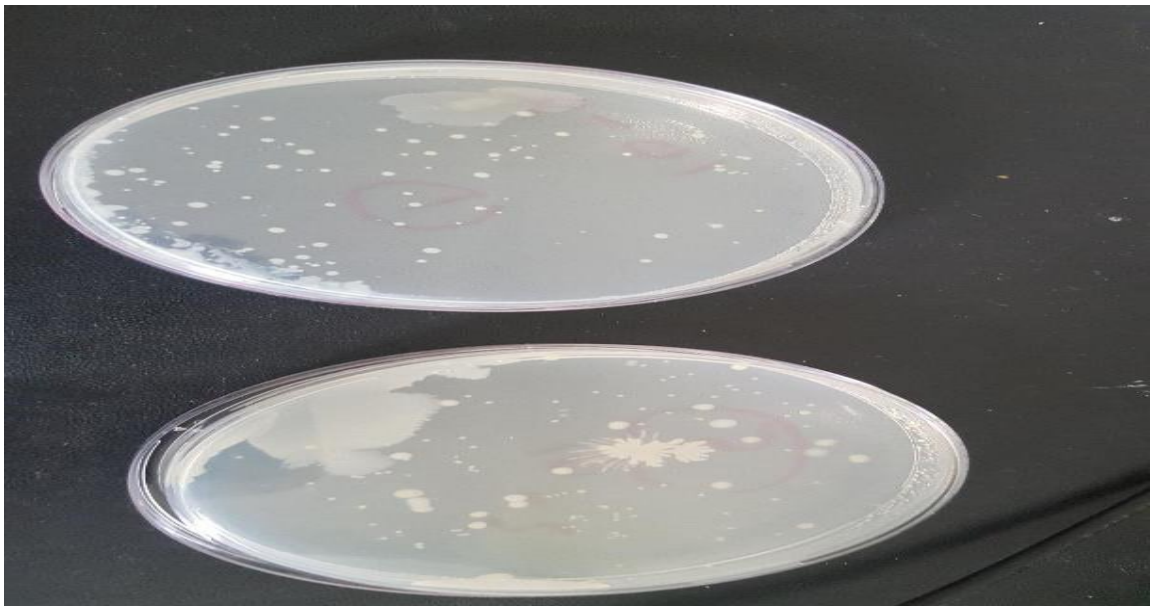

Figure 19. Colonies of total bacteria in petri dishes grown on casein

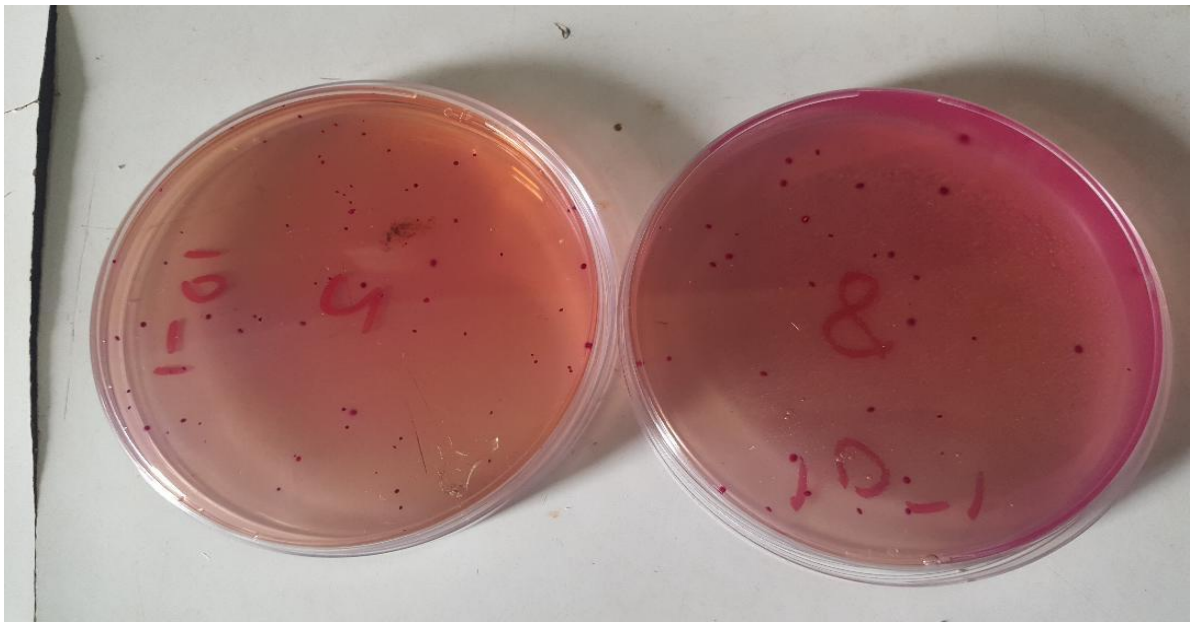

Figure 20. Colonies of coliform in petri dishes growing on violet red bile (VBR) agar

The total coliform (disease causing bacteria) counts were highest in Kwekwe River (KK) Muyuka followed by Downstream Coast Timber (CTD) Muyuka and the Benyo River (BR) in Mutengene. The least counts for disease causing bacteria were recorded at Upstream Kumba Water (KWU) and Stone Quarters Stream (STQ) Muyuka. Meanwhile the total bacteria count revealed a different and partially opposite trend from the coliform counts.

Table 3. Total bacteria and total coliform counts for the different sample sites

Sample Site	Total Bacteria Count (CFU/ml)	Total Coliform Count (CFU/ml)
KWD	4.5×10^4	50
KWU	6.8×10^5	20
DM	6.0×10^4	80
UM	8.0×10^3	50
CTD	2.0×10^4	270
CTU	1.12×10^4	90
KK	1.0×10^4	300
BR	4.4×10^4	210
STQ	2.6×10^6	20

In an inverse fashion, the Stone Quarters Stream (STQ) followed by the Upstream Kumba Water (KWU) samples registered the highest total bacteria counts. These were successively followed by Downstream Mungo River (DM), Downstream Kumba Water (KWD) and Benyo River (BR). The least total bacteria counts were recorded at Upstream Mungo River (UM) and at both Upstream and Downstream Coast Timber samples.

5.3 Major Ions

The major ions analysed were Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, PO_4^{3-} and NO_3^- . In order to achieve analytical precision of cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) and anions (Cl^-, HCO_3^-, PO_4^{3-}, and NO_3^-), ionic balance error (IBE) was used to verify precision of ions expressed in meq/l (Appelo and Postma, 1999). The IBE for all investigated samples was observed to be within a limit of ±5 %. In this study, a Piper plot of all major ions was used to characterize the 9 samples into hydro-chemical facies (Figure 21).

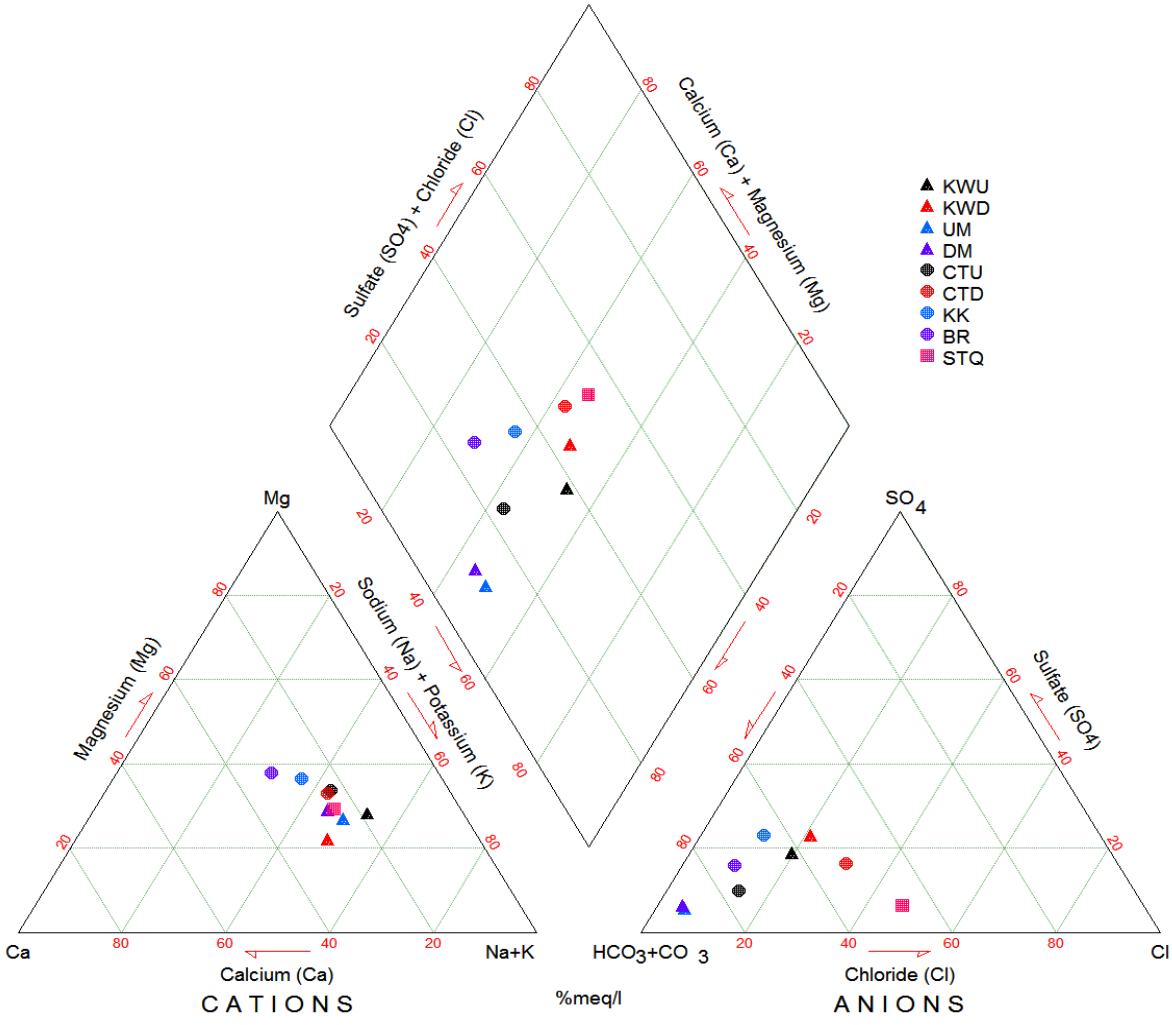

Figure 21. Piper's diagram showing water facies for the four water samples

The shapes of the Stiff diagrams for the water samples show that the waters are dominated by $Na^+ + K^+$ - HCO_3, although the Benyo River (BR) and Kwekwe stream (KK) and to a lesser extent, the (Upstream Coast Timber (CTU) and Downstream Coast Timber (CTD) rivers all show a tendency towards the Mg^{2+}- HCO_3 water type (Figure 22). The water facies revealed by the shapes of the Stiff diagrams corroborate those of the Piper diagrams.

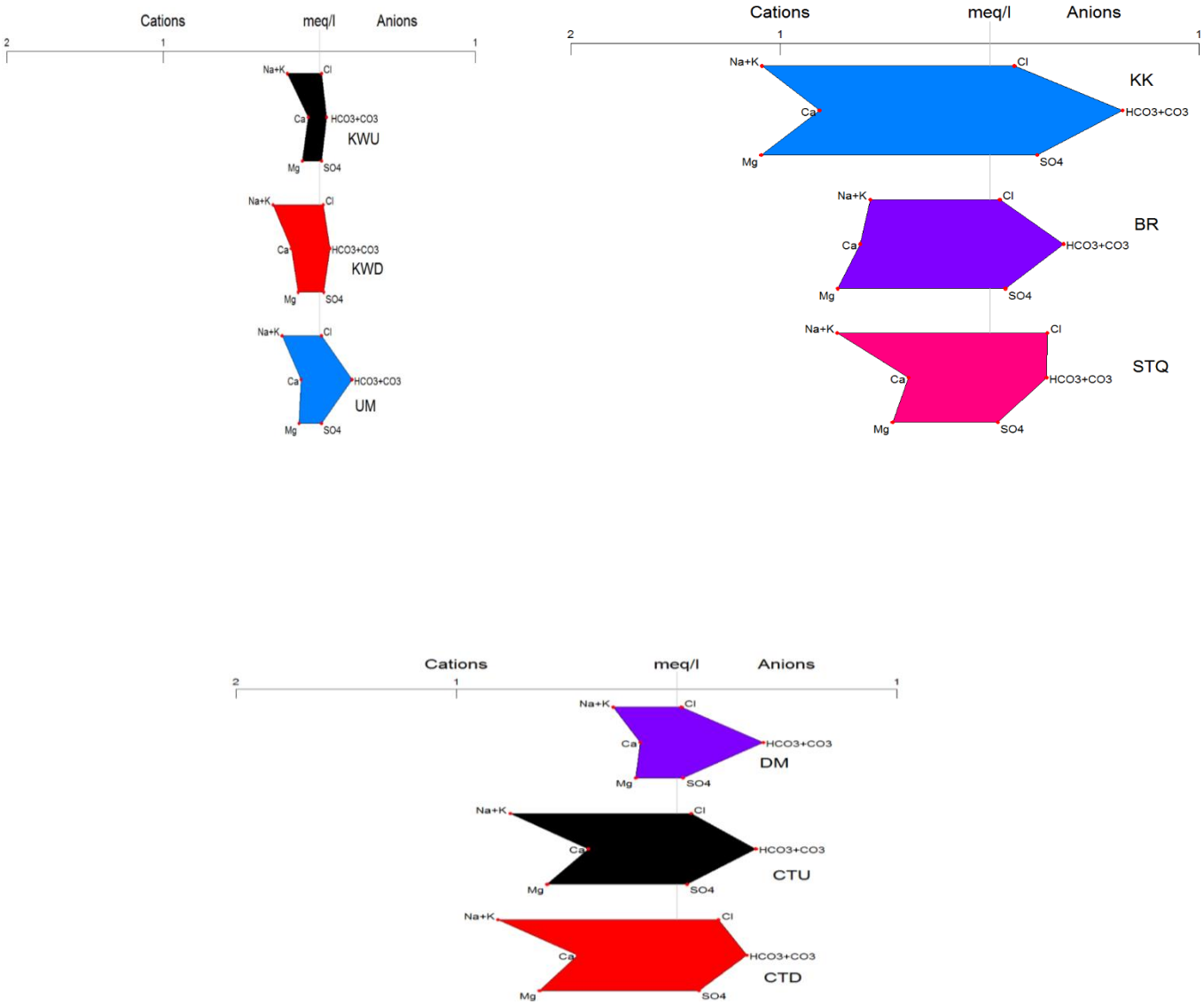

Figure 22. Stiff diagram of the various water samples with size showing degree of mineralization.

Results from the box and whisker (Figure 23) plot for all samples combined, reveals a decreasing order of magnitude for cations: $Na^{+} > Ca^{2+} > Mg^{2+} > K^{+}$. Meanwhile for all cations, the order reveals a disproportionately high magnitude of HCO_3^{-} with the decreasing evolution as follows: HCO_3- > Cl- > $NO_3^{-} > SO_4^{2-}$ as seen in Figure 24.

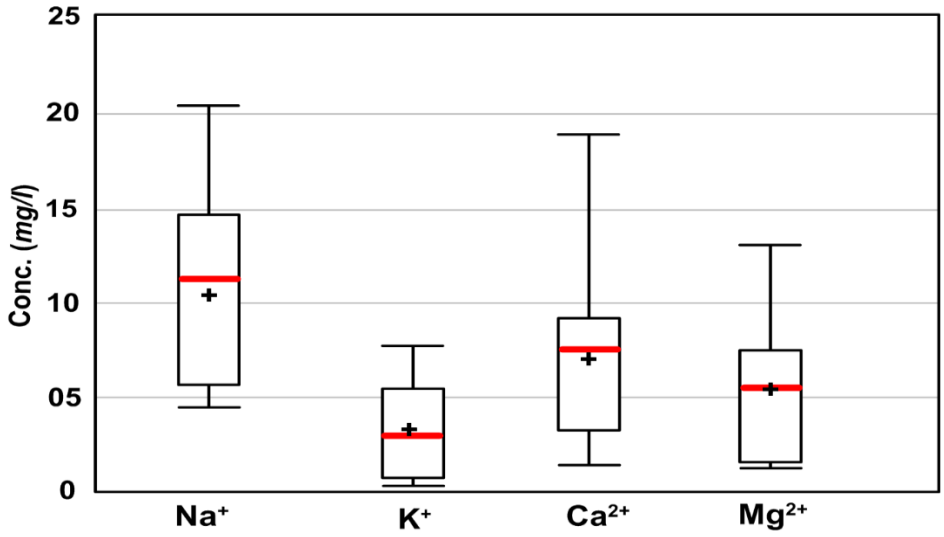

Figure 23. Box and Whisker representation for major cations

In this study the Hierarchical Cluster Analysis (HCA) was used to analyze all 9 samples with respect to all containing major ions and trace elements (Figure 25) and then separately for all major ions (Figure 26). Moreover, all combined physico-chemical parameters were also analyzed for all 9 samples (Figure 28).

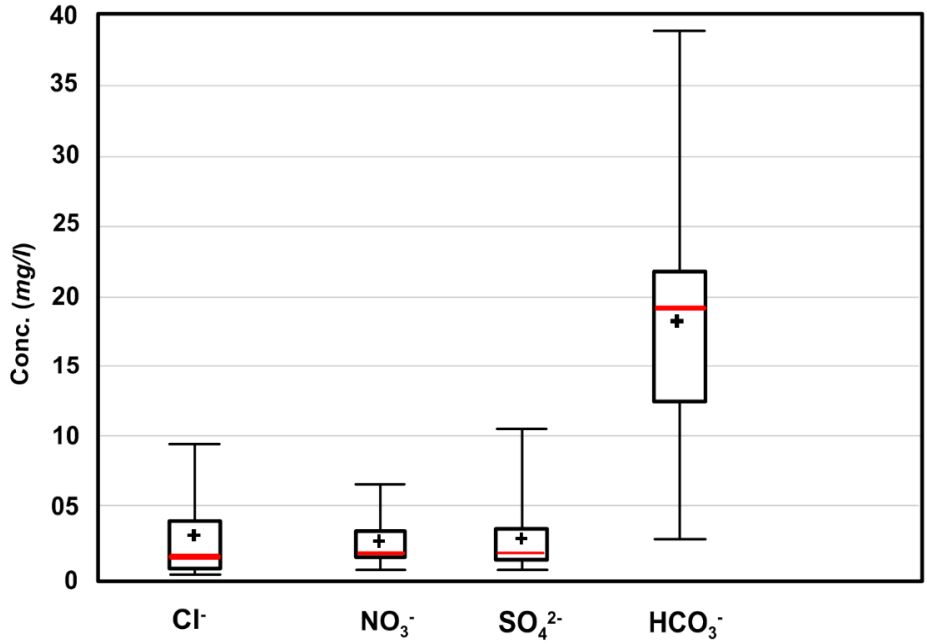

Figure 24. Box and Whisker representation for major anions

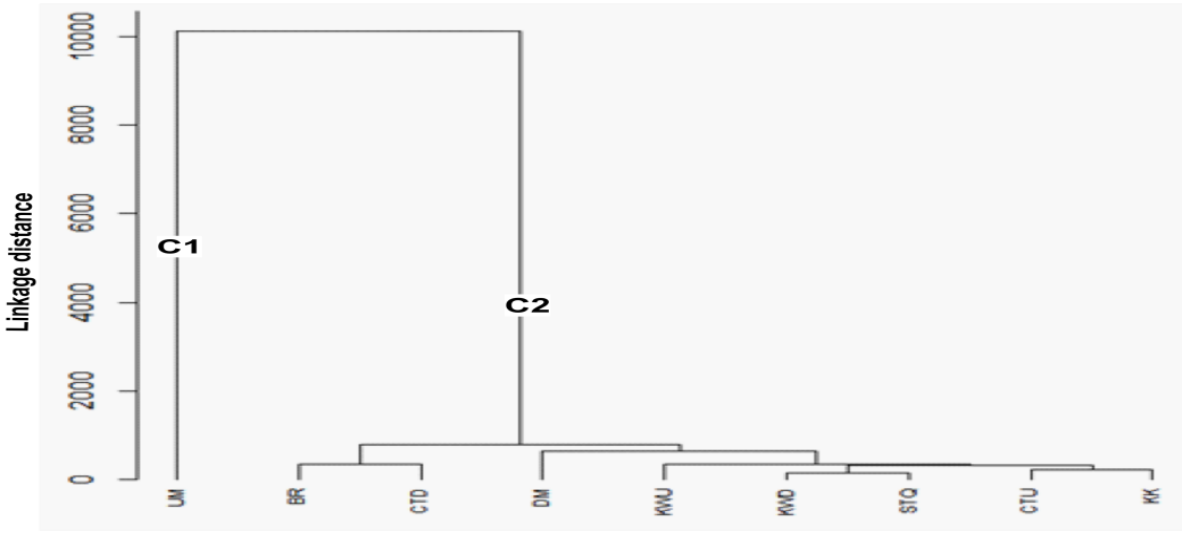

Figure 25. Dendogram in Q-mode for both major ions and trace elements in all water samples

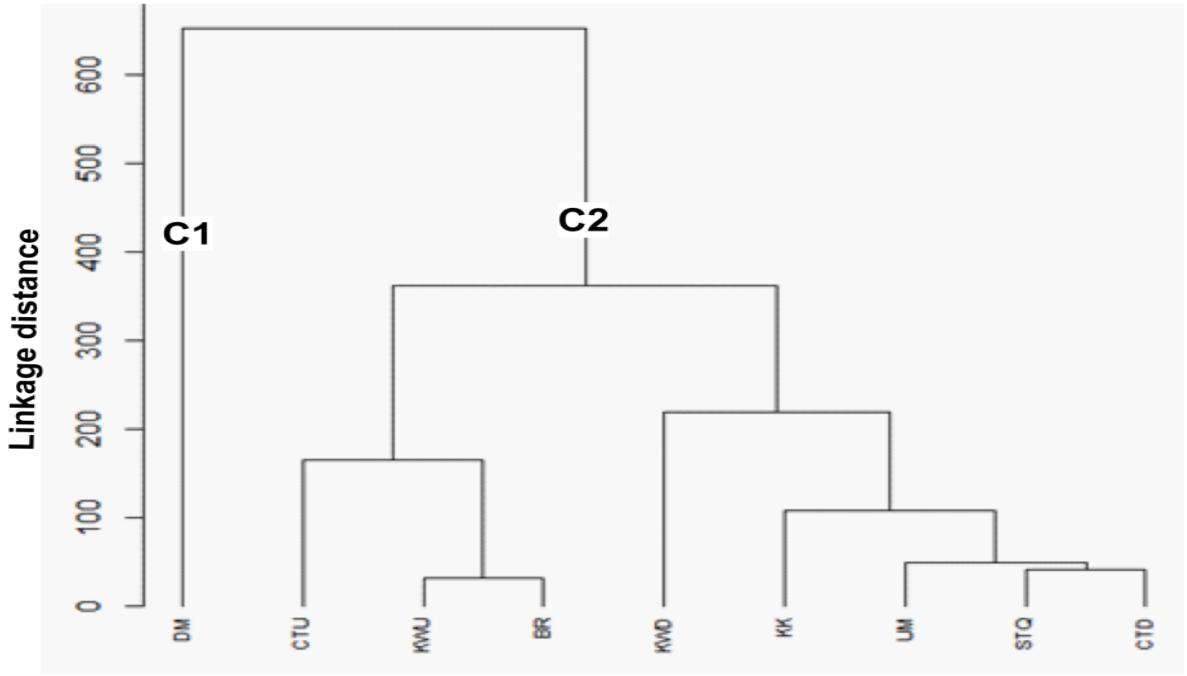

Figure 26. Dendogram Q – mode for major ions in all water samples

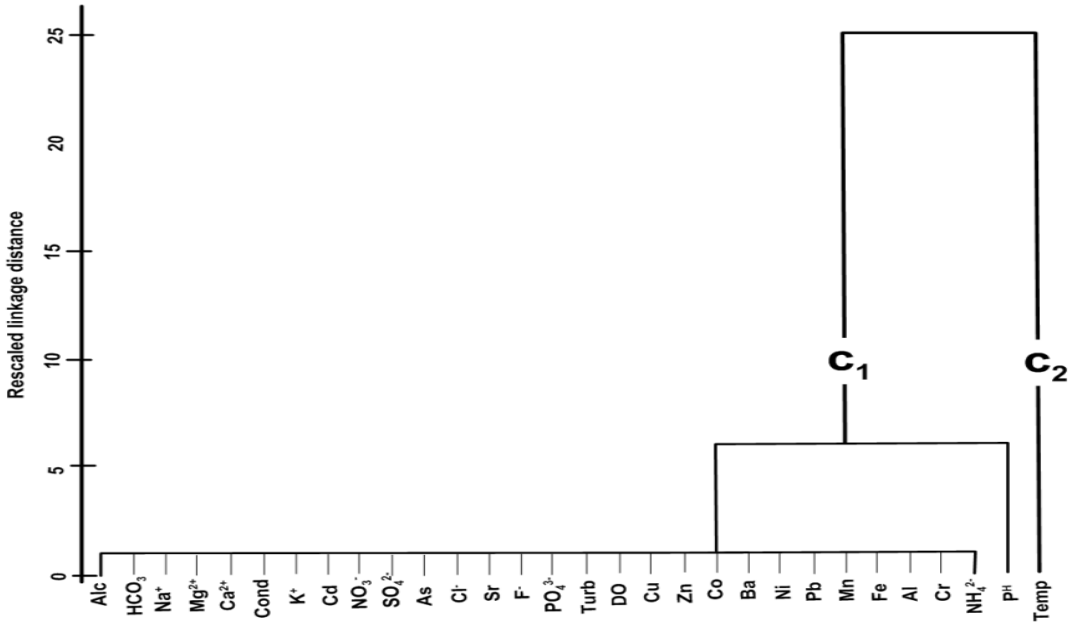

Figure 27. Dendrogram in R-mode for all physico-chemical variables in all 9 samples showing two major groups. The "C" represents cluster.

As seen from Figure 26, the Q-mode cluster analyses of all containing heavy metals and major ions resulted in two clusters, C1 and C2. The C1 constitute the Upper Mungo (UM) sample alone while the rest of the samples regrouped into the C2. The C2 is further subclustered into two subgroups with one subgroup constituting the Benyo River (BR) and Downstream Coast Timber River (CTD) meanwhile the other subgroup constitutes Downstream Mungo (DM), Upstream Kumba Water (KWU), Downstream Kumba Water (KWD), Stone Quarters Stream, Muyuka (STQ), Downstream Coast Timber River (CTD) and Kwekwe River (KK). With respect to major ions only, the Q-mode cluster analyses revealed two clusters in which the Downstream Mungo (DM) sample was isolated into cluster C1 while C2 revealed two major subclusters constituting Upstream Coast Timber (CTU), Upstream Kumba Water (KWU) and Benyo River (BR) in Mutengene. The other subcluster is composed of Downstream Kumba Water (KWD), Kwekwe River (KK), Upstream Mungo (UM), Stone Quarters Muyuka (STQ) and Downstream Coast Timber River (CTD). Meanwhile the R-mode cluster analyses of all physico-chemical parameters revealed two clusters in which temperature was isolated into the C2 cluster. While the C1 contains all the other parameters in a subgroup, the pH parameter alone constitutes a subgroup. An interpretation of various clusters and subclusters with respect to their geochemical inter-relationships is presented in Chapter 6.

The correlation matrix was used to decipher the associations between variables in order to reveal coherence of the data set thereby demonstrating the overall influence in the participation of the different hydrochemical parameters (Helena et al., 2000). From the PCA based on the R-mode, 5 main factors or groups were realized from the plot, for which 3 factors were predominantly influential. As derived from the rotation sum of squared loadings in Table 4 and Figure 28, Factors 1, 2 and 3 consist of all heavy metals parameters and cumulatively make up 75.8% of the total variance in all the samples. Meanwhile factors 4 and 5 constitute 16.3% of the total variance. These percentage proportions are derived from the varimax rotated factor loadings of all 5 components as elaborated in Table 5.

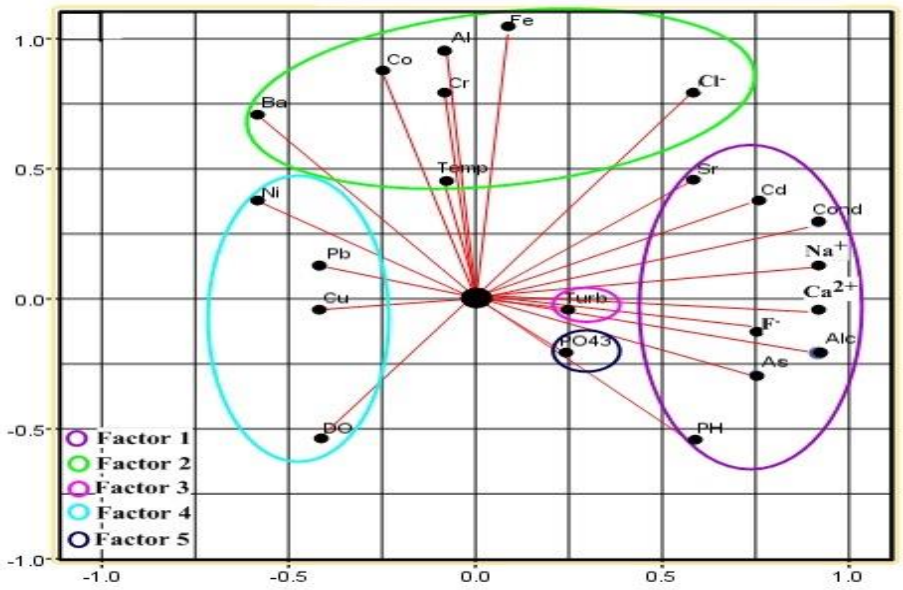

Figure 28. Factors summarized and grouped showing the geochemical relationship of variables in naturally occurring river water samples revealing basically water-rock interaction for factor 1, and natural trace element affinities (just like in altered natural systems) for factor 2 and factor 3.

Table 4: Summary of extraction method component analysis

Component	**Rotation sum of squared loadings**		
	Total	% of variance	Cumulative %
Factor 1	11.685	40.294	40.294
Factor 2	7.180	24.757	60.051
Factor 3	3.167	10.922	75.973
Factor 4	2.557	8.818	84.791
Factor 5	2.172	7.491	92.282

Table 5: Rotated Component Matrix[a]. Varimax rotated factor loadings for five experimental variables in R-mode. Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization with rotation converged in 8 iterations.

	Components				
	1	2	3	4	5
Temp	-.108	.434	-.308	-.709	.181
DO	-.405	-.485	-.192	.035	-.009
Cond	**.910**	.261	-.236	.144	.153
Turb	.200	-.056	.115	**.906**	-.018
PH	**.610**	-.573	-.067	.427	.119
Alc	**.738**	-.158	-.525	.039	.087
Na	**.937**	.081	-.161	-.100	.257
K	**.879**	.214	-.248	-.197	.268
Mg2	**.951**	-.066	-.219	.156	.122
Ca2	**.958**	-.019	-.142	.238	.047
F	**.705**	-.093	-.007	-.574	.194
Cl	.537	**.696**	-.072	-.340	.176
NO3	**.813**	-.317	.029	.416	-.228
PO43	.118	-.174	.017	-.115	**.933**
SO42	**.915**	-.243	-.201	-.101	-.194
HCO3	**.738**	-.158	-.525	.039	.087
Al	.013	**.959**	-.054	-.006	.114
Cr	-.055	**.825**	.166	.480	.208
Mn	-.050	**.977**	.095	-.135	-.112

Fe	.037	**.988**	-.068	-.095	-.031
Co	-.236	**.849**	.371	-.084	-.280
Ni	-.442	.398	**.660**	-.032	-.396
Cu	-.315	.018	**.752**	.408	.354
Zn	-.326	.077	**.807**	.259	.193
As	**.727**	-.254	-.231	-.034	-.377
Sr	**.630**	.459	-.181	-.315	.507
Cd	**.730**	.446	-.194	.451	-.063
Ba	-.459	**.779**	.131	-.097	-.380
Pb	-.187	.028	**.921**	.000	-.172

The concentration of sodium in all water samples ranged from 4.46 mg/l to 20.36 mg/l with Up-stream Kumba Water (KWU) registering the lowest value with Kwekwe River having the highest value respectively. This was followed by CTD, CTU and STQ in that order. The concentrations of all other cations (K^+, Ca^{2+}, Mg^{2+}) showed a similar trend as sodium and electrical conductivity. All water samples are well below the WHO (2004) standard threshold of 200 mg/l for Na^+ and 12 mg/l for K^+.

Contrary to the cations that display a consistent trend among all samples, the results of anions show a diverse picture. While phosphate concentrations were only recorded at Coast Timber River samples, those of chloride albeit generally low, were highest at STQ followed by CTD and KK. The concentrations for nitrates ranged from 0.63 mg/l to 6.86 mg/l with the highest value at KK, BR and CTD in that order while UM and STQ had the least values. Fluoride concentration was highest at CTD followed by KK while KWU and UM had the lowest concentrations. All registered concentrations of all anions fell below the WHO (2004) standard thresholds.

Table 6: Concentration for major ions from different samples

Sample	CATIONS (mg/l)					ANIONS (mg/l)			
	Na^+	NH_4^+	K^+	Mg^{2+}	Ca^{2+}	F^-	Cl^-	NO_3^-	PO_4^{3-}
KWU	4.46	0	0.46	1.33	1.44	0.07	0.52	1.41	0
KWD	6.5	0	0.57	1.65	3.6	0.27	0.91	2.28	0
UM	5.01	0	0.82	1.59	2.34	0.16	0.47	0.63	0
DM	5.96	0	1.13	2.26	3.32	0.33	0.74	1.51	0
CTU	14.43	0	5.02	7.15	8.04	0.49	2.32	1.76	0.94
CTD	15.13	0	6.03	7.57	9.01	1.96	6.72	3.56	0.4
KK	20.36	0	7.93	13.27	16.3	1.23	4.16	6.86	0
BR	11.34	0	3.05	8.82	12.4	0.2	1.7	6.83	0
STQ	13.29	0	5.88	5.64	7.77	0.63	9.76	0.97	0
WHO	200	0.50	12	125	75	2.00	250	50	5

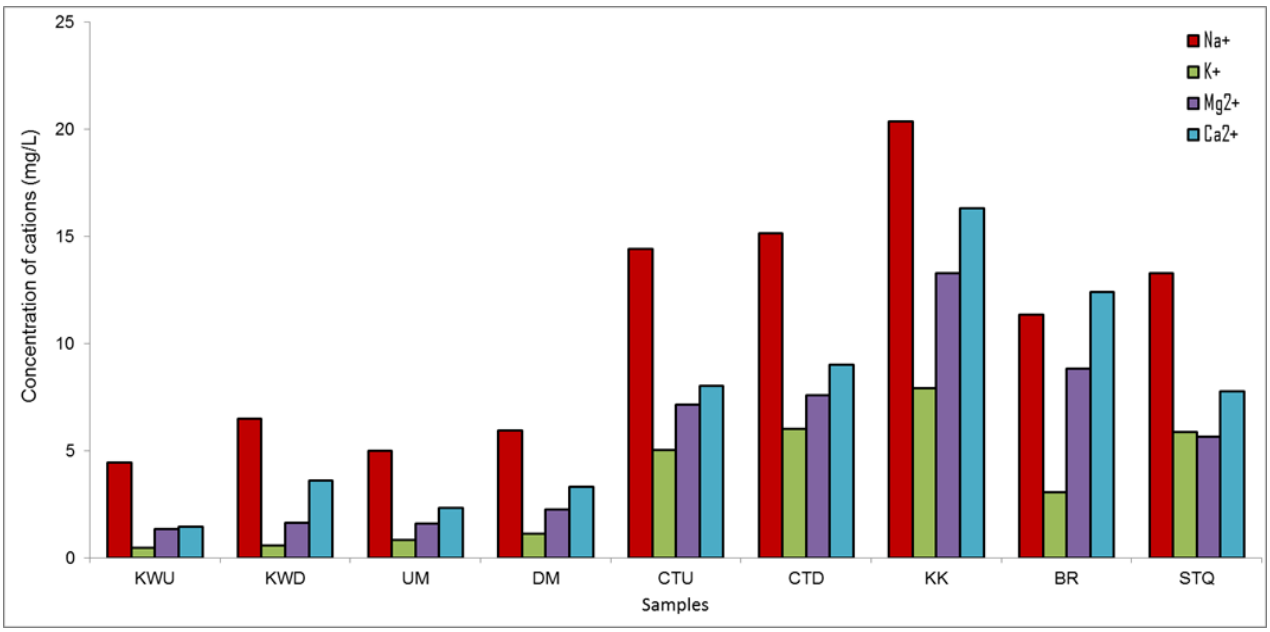

Figure 29. Histogram representing cationic concentrations of samples

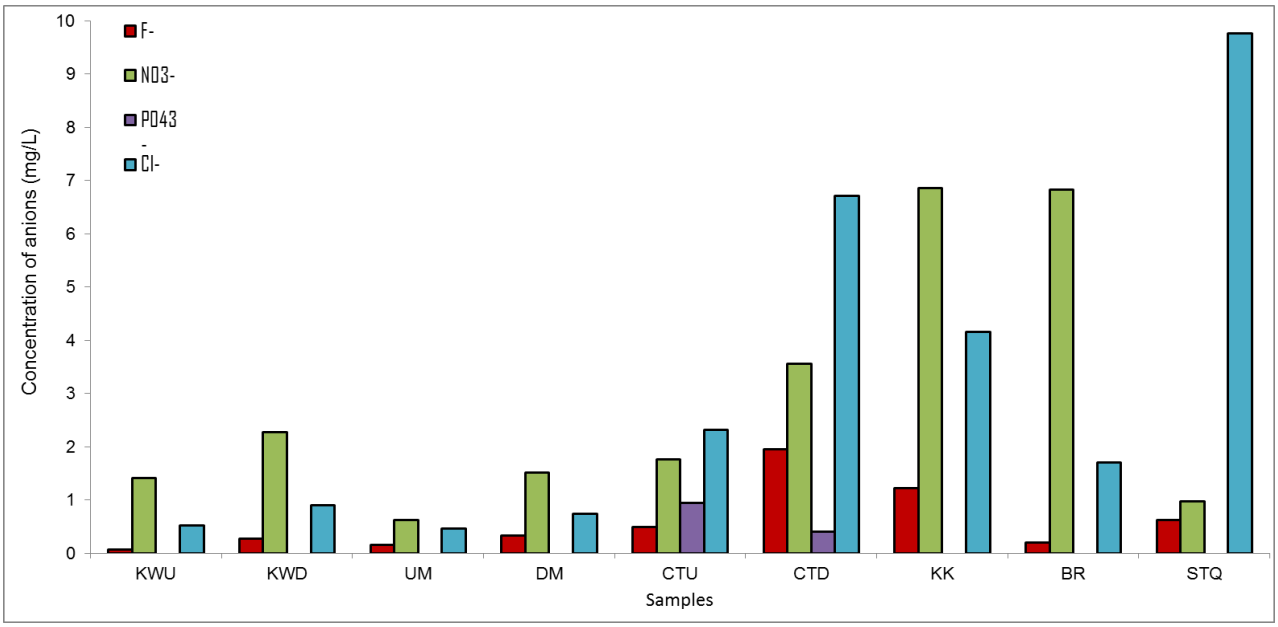

Figure 30. Histogram representing anionic concentrations of samples

5.4. Trace Elements

As alluded to in Chapter 4, the trace elements analyzed were As, Al, Cd, Cr, Pb, Sr, Mn, Fe, Cu, Co, Ni, Zn and Ba. Results for the analyses of trace elements revealed a more diversified trend among all samples. With the notable exception of Fe, Al, Mn, and Cd in one or many samples, the concentrations of trace elements for most samples were below the WHO (2004) thresholds.

While still within safe levels and below the WHO standards threshold, the concentration of lead was highest at Downstream Kumba Water (KWD) followed by Upstream Mungo River (UM), Benyo River (BR) and Downstream Coast Timber River (CTD) in that decreasing order. There was no detection of lead from the Kwekwe River sample. While the concentration of aluminum was negligible from the Downstream Coast Timber sample, the Stone Quarters Stream sample had the highest value followed by relatively lower values for Upstream Coast Timber and both Kumba water samples which largely have similar concentrations.

While chromium was negligible in all samples, the trend for iron and manganese was similar to each other with extraordinarily high values for the Stone Quarters stream followed by both Kumba water samples. This particular trend was also followed by cobalt concentrations in all samples

albeit with very infinitesimal concentrations. The concentration for barium was highest at Stone Quarters stream followed by the Kumba Water and Mungo River samples. The concentration of arsenic was high at Kwekwe River followed by near insignificant values for the other samples while cadmium was highest at Benyo River followed by Stone Quarters stream, Kwekwe river and the Coast Timber river samples in that decreasing pattern. Zinc and copper had significantly low values for Downstream Kumba water and the Benyo River in Mutengene while Strontium was highest at Stone Quarters Stream followed by both Coast Timber River and Kwekwe samples in that order.

Table 7: Concentration of trace elements from all samples

Sample	Al	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Sr	Cd	Ba	Pb
	µg/l	*µg/l*	*µg/l*	*µg/l*	*µg/l*	*µg/l*	*µg/l*	*µg/l*	*µg/l*	*µg/l*	*µg/l*	*µg/l*	*µg/l*
UM	56.75	0.00	32.66	176.69	0.37	0.43	1.53	6.83	0.01	0.01	27.30	23.18	0.45
KWD	104.07	0.00	110.89	644.56	1.25	1.45	3.25	10.15	0.25	0.01	23.52	30.18	1.65
CTU	168.24	0.00	6.10	11.93	0.07	0.18	2.52	6.19	0.25	0.25	48.45	4.05	0.13
CTD	3.32	0.00	30.64	211.51	0.33	0.43	1.13	5.71	0.05	0.25	54.27	8.25	0.38
BR	60.78	0.00	22.16	203.36	0.44	0.55	2.36	7.41	0.31	0.05	127.96	13.09	0.45
STQ	499.56	0.00	380.58	10113	1.83	0.95	1.30	5.69	0.04	0.31	118.70	47.37	0.31
DM	29.77	0.00	36.88	170.90	0.48	0.50	1.13	4.97	0.01	0.04	31.08	24.39	0.17
KWU	104.08	0.00	58.73	604.85	0.76	1.07	1.17	3.91	0.21	-0.01	21.04	25.52	0.12
KK	67.04	0.00	7.14	6.07	0.06	0.08	0.16	2.29	2.29	0.21	109.09	6.07	0.00
WHO	200	50	400	300		20	2000	3000	10.00	1500	6.00	300	10.00

5.5 Results of Health Risk Assessment

After computing the values into the above equation, the Pollution Indices (PI) for Fe at Kwekwe Stream (KK) in Muyuka had the least value at 0.26. Meanwhile the PI for Fe for Stone Quarters Stream (STQ) in Muyuka was extraordinarily high at 438.23 followed by that of Downstream Kumba Water (KWD) at 27.93 and Upstream Kumba Water (KWU) at 26.20. In the case of Al, the highest value for PI was derived at Stone Quarters stream (STQ) Muyuka with 32.47 while Downstream Coast Timber River (CTD) in Muyuka represented the least value at 0.25. Meanwhile for Mn, the least and highest values for PI were represented by Upstream Coast Timber River (CTU) in Muyuka at 0.23 and Stone Quarters stream (STQ) Muyuka at 12.37 respectively.
Cadmium had the least and highest values for PI from Upstream Kumba Water (KWU) at 45.60 and the Benyo River (BR) at Mutengene with 277 respectively. It should be noted however, that the PI values are commensurate to the concentration of the trace metals in the various samples. Hence the PI indices for Fe in STQ and for Cd in CTU, CTD, STQ, BR and KK are above the critical value of 100, all indicating heavy metal pollution.

Table 8: Pollution Indices (PI) of influential elements

Sample	UM	DM	CTU	CTD	KWU	KWD	STQ	BR	KK
Fe	7.66	7.41	0.51	9.17	26.20	27.93	438.23	8.81	0.26
Al	3.70	1.93	10.93	0.25	6.76	6.76	32.47	3.40	4.36
Mn	1.06	1.20	0.23	1.00	2.00	3.60	12.37	0.72	0.27
Cd	59.15	67.34	105.00	117.58	45.60	51.00	257.18	277.06	236.36

Meanwhile the average daily dose (ADD) for Al in Stone Quarters stream (STQ) Muyuka is $1.3x10^{-2}$mg/L/day; Fe in Stone Quarters stream (STQ) Muyuka is $2.8x10^{-1}$mg/L/day while Fe in Downstream Kumba Water (KWD) is $1.8x10^{-2}$ mg/L/day. For Mn in Stone Quarters stream (STQ) Muyuka, the average daily dose (ADD) is $1.0x10^{-2}$mg/L/day and meanwhile Cd in the Benyo River (BR) at Mutengene gave an average daily dose (ADD) of $3.5x10^{-3}$mg/L/day

Table 9: Average daily doses (ADD) of influential trace elements

Sample (mg/L/day)	UM	DM	CTU	CTD	KWU	KWD	STQ	BR	KK
Fe	$4.9x10^{-3}$	$4.7x10^{-3}$	$3.3x10^{-4}$	$5.8x10^{-3}$	$1.7x10^{-2}$	$1.8x10^{-2}$	$2.8x10^{-1}$	$5.6x10^{-3}$	$1.7x10^{-4}$
Al	$1.6x10^{-3}$	$8.2x10^{-4}$	$4.6x10^{-3}$	$9.2x10^{-5}$	$2.9x10^{-3}$	$2.9x10^{-3}$	$1.3x10^{-2}$	$1.7x10^{-3}$	$1.8x10^{-4}$
Mn	$9.0x10^{-4}$	$1.0x10^{-3}$	$1.6x10^{-4}$	$8.5x10^{-3}$	$1.6x10^{-3}$	$3.0x10^{-3}$	$1.0x10^{-2}$	$6.1x10^{-4}$	$2.0\ x10^{-4}$
Cd	$7.5x10^{-4}$	$8.6x10^{-4}$	$1.3x10^{-3}$	$1.5x10^{-3}$	$5.8x10^{-4}$	$6.5x10^{-4}$	$3.3x10^{-3}$	$3.5x10^{-3}$	$3.0x10^{-3}$

5.6 Statistical Analyses

The use of multivariate statistical techniques was applied in order to identify the hydrochemical characteristics of the samples and to provide knowledge to the physico-chemical processes occurring in these water bodies, to understand the petrology of the rocks from which they issue and on which they flow (Guler et al., 2002). As observed from the Piper diagram in Figure 21, the hydrochemical classification revealed two major water types (NaK- HCO_3 and CaMg- HCO_3). The water facies revealed by the shapes of the Stiff diagrams largely corroborate those of the Piper diagram and also give an indication to the rock types and the ongoing mineralization processes especially through the dissolution of silicate minerals. Meanwhile the presence of samples with slight chloride and nitrate facies is indicative of both anthropogenic contamination and petrological origins (Amadou et al., 2014; Affum et al., 2015; Menció et al., 2016; Rokotondrabe et al., 2018).
The box and whisker plot for all samples also revealed a water type dominated by HCO_3 in combination with both alkali (Na, K) and alkali earth metals (Ca, Mg). Meanwhile, both the Q and R-modes of the dendrograms revealed very few clusters indicating a much narrow and specific origin for water.

Surface water as well as groundwater quality are influence of major anions and cations through cation exchanges, mineral dissolution of soils and through the chemical weathering of silicate rocks (Affum et al., 2015). With respect to the Principal Component Analyses (PCA) in Figure 28, factor 1 has high loadings for the major cations/anions (except for Cl^-) and for As, Sr and Cd. This

factor alone contributes 40.3% of the total variance and is highly linked to weathering and dissolution of silicate minerals through water-rock interaction. Factor 2 has high loadings for Fe, Mn, Al, Cr, Co, and Ba and accounts for up to 24.6% of the total variance. This factor is linked to Cation Exchange Capacity (CEC) of colloidal Fe, Mn and Al whose small sizes and non-crystalline structure give them very high negative surface charge for adsorption of compatible trace elements Cr and Co and equally the adsorption of easily exchangeable High Field Strength (HFS) large ion lithophilic trace elements such as Ba (Tanyileke, 1996; Mistra, 2012). Factor 3 exhibits high loadings for Pb, Zn, Cu and Ni, making up 10.9% of the total variance. This factor is a natural association of charcophile and or siderophile elements (Mistra, 2012). Factors 4 and 5 have high loadings for turbidity and PO_4^{3-}, contributing 8.8% and 7.5% of total variance respectively. This factor can be linked to anthropogenic activity (Affum et al., 2015; Verla et al., 2014). The weathering of various silicate minerals, which form the building blocks of rocks, is also dependent on the relative abundance of various ions and trace metals in their respective host rocks as well as their solubility (Pandey et al., 1999).

The water types in the area of study are dominated by the NaK-HCO_3 and CaMg- HCO_3 facies. This corroborates with other recent studies that have been conducted in other areas in Africa with similar subsoil geology. The pH for all the 9 samples ranged from 6.90 – 8.28 indicating a neutral to slightly acidic assemblage. The pH is most acidic at the Stone Quarters Stream (STQ) indicating an anaerobic environment in which there are visibly very few aquatic organisms (Figure 31).

The water samples around Kumba and the Mungo to a lesser extent generally reveal slightly higher concentrations for iron, aluminum and manganese which may be indicative of a geologic substratum dominated by lateritic rocks. This gives reddish to light brown coloration that becomes more evident downstream due to the leaching of ferrallitic soils which constitutes the topsoil of the area. On the other hand, the presence of higher concentrations of lead, barium, copper, cobalt and zinc can be attributed to anthropogenic activities arising from diverse local artisanal and industrial processes. They are also characterized by high turbidity, lower conductivity, total dissolved solids and dissolved oxygen.

The samples of the water bodies around Muyuka and Mutengene townships (with the exception of STQ) generally have low turbidity with higher pH, conductivity, total dissolved solids and dissolved oxygen. These waters are more influenced by the HCO_3 -CO_3 and preferentially Na and Ca which form the building blocks of basaltic rock minerals like plagioclases, olivine and pyroxenes.

Figure 31. Stone Quarters Stream displaying a reddish-brown precipitate. Muyuka, Cameroon

The Stone Quarter Stream in Muyuka exhibited a unique trend. The concentrations of Fe, Mn and Al were disproportionately higher with Fe twenty-times higher than the second highest value at KWD. Meanwhile Mn was four-fold higher than the second highest value at KWD and Al four-fold higher than the next highest value at CTU. Due to an evident lack of considerable industrial activity along the course of the STQ, it can be inferred that the source of very high Fe, Mn and Al concentration should be lithogenic from a correspondingly iron rich bedrock. The insoluble ferric ions Fe (III) precipitates which impart a reddish-brown coloration (Figure 31) are indicative of the oxidation of much soluble ferrous ions Fe (II) with the eventual availability of oxygen through the attainment of aerobic conditions. The likely presence of high Fe (II) concentration is also contingent on the relatively favorable low pH. This trend is similar for Mn. Though the number of disease-causing bacteria is relatively low in the STQ samples, it represents by far the highest total bacteria count. This agrees with Ekström et al. (2015) which stipulates the proliferation of iron-oxidizing chemotrophic bacteria in iron rich waters under anaerobic conditions. These bacteria survive through the oxidation of ferrous iron as their energy source.

Meanwhile, the relatively high concentrations for arsenic, chromium, cadmium and strontium in KK, BR and the Coast Timber River samples can be attributed to both lithogenic and anthropogenic activities. While both the BR and KK are used as receiving channels for excrements and waste from key slaughter houses, the area around BR is further dominated by industrial and local artisanal activities as well as the national oil refinery at Limbe, Cameroon. This could be contributing to atmospheric deposition of trace elements in crude oil. The relative high concentrations of lead, cobalt, copper, barium and nickel in the Downstream Kumba water sample can be alluded to

as anthropogenic sources with the city being the largest and most economically active in the whole region.

6 CONCLUSIONS AND RECOMMENDATIONS

This chapter gives a brief conclusion on the key aspects that formulated the results and discussion of this project as it pertains to the suitability of these water bodies for recreational activities (swimming), domestic usage (cooking, laundry, washing and other household chores) and in some cases, for drinking. The aspects range from microbial analysis, and analyses of physicochemical parameters. The chapter further highlights the limitations of this particular work and potential opportunity for further research as well as outlines some socio-economic recommendations that could be taken to mitigate and alleviate the problem of water pollution both in a national and regional context.

6.1 Conclusions

The results show that these water bodies are unfit for certain current uses due to biological, chemical (elevated concentration of some trace elements) and to some extent physical (turbidity) pollution. While most of the samples reveal pH values within the WHO acceptable levels, the STQ stream has a slight acidic pH and a correspondingly low dissolved oxygen concentration. This is likely due to its anaerobic marshy environment and the presence of trace elements facilitating redox reactions. Samples with high turbidity and suspended solids all displayed a corresponding decrease in total dissolved solids, electrical conductivity and alkalinity. This correlates to their substratum source. The waters with higher total dissolved solids, alkalinity and electrical conductivity are underlain by readily dissolved mineral rich basaltic substratum while those with high turbidity values and suspended solids flow over ferralitic and lateritic substrata.

The multivariate statistical analyses helped in identifying areas with higher contamination. In most of these water bodies, the contamination is driven by rock-water interaction which is linked to the chemical weathering of silicate minerals, but also from the presence of bacteria. The total coliform counts reveal that all samples are unfit for human ingestion in accordance with the WHO standards. Exposure of the various riparian populations to such bacteria usually leads to helminth infection and water-borne diseases such as diarrhea, cholera, dysentery and typhoid. While the total coliform counts were highest in the KK and CTD samples, the STQ shows highest counts for total bacteria indicating the presence of chemotrophic bacteria that oxidize ferrous iron.

As alluded in the discussion, the waters also reveal the domination of (HCO_3), (Na, K) and (Ca, Mg) facies, and major trace element concentrations (Fe, Al, Mn, Cd) are indicative of the influence of rock-water interactions and to a lesser extent by anthropogenic activities. Meanwhile the health risk analyses reveal pollution indices for Fe and Cd above the critical value of 100 for one or more samples.

This study represents a maiden effort towards the establishment of water quality data for a number of major water bodies on the eastern flank of Mount Cameroon. It will be helpful in laying the foundations for the creation of a microbiological and hydrogeochemical baseline of data that will be useful for human protection as well as for sustainable development around the study area. The study helps in exploring and quantifying the contribution of a non-point source of contaminants to water quality status of these streams. The study reveals the water bodies are unfit for human consumption, recreational activities and in some cases, for irrigational purposes.

6.2 Recommendations

In 1996, Cameroon enacted the law (Law N0. 96/12 of 5th August 1996) that provided the legal provisions for the environmental management of industrial contaminants including heavy metals and nutrients into aquatic ecosystems. However, pollution levels (trace elements and disease-causing microbes) remain exceedingly high in many localities including those on the eastern flank of Mount Cameroon. Hence, the prevailing regulatory prescriptions have done little in real improvements on the ground as it pertains to terrestrial and water pollution. Some of the impediments towards the implementation of existing environmental policies depend on factors ranging from;

- Complex institutional set-up with overlapping roles and responsibilities with regard to inspection and enforcement, thereby creating inter-institutional conflicts;
- Scarce budgetary allocation to enforce pollution standards especially by companies. Hence, continuous shortage of modern and environmentally friendly equipment and machinery;
- Shortage and lack of expert personnel and infrastructure for water analyses;
- Inadequate number of waste monitoring, control and treatment facilities (controlled landfills, treatment plants);

- Limited community awareness and involvement in sanitation (water-borne diseases) and other environmental problems and solutions. Further awareness and proper management of agro-silvo-pastoral chemical inputs should be enhanced;
- Insufficient monitoring and compliance. The absence of a list specifically defining industrial waste, a database on water quality and clear regulations on coastal pollution;
- The absence of an integrated policy for household waste management (integration of the resource aspects, organization, education and awareness of the population in terms of hygiene and sanitation);
- The non-application of the legal instruments governed by the law on classified establishments and the practice of the polluter-pays principle in accordance with the texts of the Framework Law on the environment are not respected;
- Inadequate coordination between stakeholders (Billa, 2009).

It is important to note that, the socio-economic and political circumstance of a region or more specifically a country can reduce the ability to deploy technical solutions towards mitigating surface water contamination. Hence the level and scale of technological prescriptions towards combatting water pollution would be lower in Cameroon than in western nations such as Canada. However, in other to reduce surface water pollution at the local region under study, some remedial actions (some of which are already in place in few towns such as Buea and Limbe) can be emulated in other localities like Kumba, Muyuka, Mutengene and Tiko. Some of these solutions could be as follows.

Sewage and wastewater treatment processes can significantly reduce biochemical contamination of surface waters. Around this region, the lone sewage treatment complex is found at the University of Buea, where sewage is being processed into the generation of biogas which supplies energy for the University. With the provision of necessary funding, such complexes could be expanded in the city of Kumba and other towns such as Tiko, Muyuka and Mutengene. This would not only alleviate biological contamination but would help generate energy for these local communities. The absence of wastewater treatment facilities means the bulk of used water originated from urban areas is being wantonly drained into valleys and onto their containing water bodies. The installation of wastewater treatment facilities would help reduce physical, chemical and/or biological contamination of these waters.

Greywater containing suspended solids, greases and fats, pathogens and chemicals derived from soaps and detergents, continues to be a potential source of contamination as it is being disposed indiscriminately ending up into these water bodies. The installation of low cost, small scale, household level greywater treatment systems could be used to treat municipal effluent to produce environmentally friendly and irrigation suitable waters. However, in order to reduce most municipal wastes in the first place, the local communities should create efficient waste collection systems and encourage adherence to sorting and proper disposal of wastes. This can range from motor oil or other automotive fluids, pills, liquid or powder medications or drugs, household chemicals, batteries, scrap metal and biodegradable/organic materials. With the prevailing inexistence of such waste disposal network in most localities, they all end up at the water bodies.

Due to intense utilization of agricultural enhancing chemicals by both large agro-industrial plantations and small farmers, leaching of agricultural fields is a major source of surface water contamination on the Eastern flank of Mount Cameroon. Hence the population should be encouraged to use more organic compost manure and reduce the use of pesticides, herbicides, fertilizers that enter these waters. With the provision of funds, the creation and efficient management of municipal landfills and incineration plants could greatly reduce the problem of garbage and hence alleviate the water contamination. The garbage in these landfills can be periodically incinerated to generate energy for the local communities (Monterey, 2012; Simsbury, 2019).

Most riverine communities along these water bodies lack pipe-borne water for drinking and are therefore most susceptible to water pollution. In order to mitigate contamination of the population through the consumption polluted waters, the following simple purification remedies can be recommended.

The provision of filters to purify water can be achieved at the local community, household and even individual levels. The government, in partnership with the local communities, should allocate free provision of filters especially in the economically poorer and high-risk rural communities. Boiling water is simple and easy. It enables water to be drinkable as it kills water-borne bacteria, parasites and viruses. Though it does not improve and may actually worsens the taste, boiling water it significantly kills pathogens. Chlorination, one of the most cost-effective public health innovations in the supply of potable water, can also be readily expanded in communities along the Eastern

flank of Mount Cameroon. The application of chlorine eliminates disease-causing pathogens in water and is globally the most commonly used disinfectant as it is cheap, effective and safe making it a viable option for water purification in many rural areas (WCC, 2008). The introduction of ozonation and ultraviolet germicidal irradiation can also be used to disinfect microbes as a viable water treatment process for domestic consumption. Water collected from these water bodies can also be treated with activated charcoal in order to remove contaminants and impurities through chemical adsorption process. The charcoal carbon filters are very efficient in the removal the chlorine, fluoride, sediments, volatile organic compounds (VOCs), as well as taste and odor.

The outcome of this research will help in guiding the decision-making process in the provision of data necessary for the protection of surface water resources on which the population of the eastern flank of Mount Cameroon depends as well as mitigate the risk of contamination to the population of these communities. Globally, the world's population continues to climb past seven billion people, it is critical to incorporate innovative procedures that will enable policy and decision-makers make bold technological and financial investments that will result in providing safe drinking water to large ill-served communities throughout the world.

The disproportionately high concentrations of trace elements (Fe, Mn and Al) in the Stone Quarters Stream merits further research. This research should aim at determining the specific sources, redox species and redox dynamics of these ions along the water course from its source point to where it enters the Coast Timber River. This can be achieved by multiple sampling sites and a more detailed study of the specific wastes being disposed into the stream from domestic sources along its entire course.

It is worthwhile noting that the impact of both long and short term climate changes and the potential modifications of rainfall patterns, flow volumes and the overall concentration of contaminants were not factored in this study. In order to determine the influence of seasonal climatic factors, sampling and analyses should also be undertaken for the dry and rainy season and the ionic concentrations and microbiological parameters compared to account for any potential discrepancies. A more expanded study involving more water-courses with the identification of their sources, the determination of flow volumes and dissolution rate of contaminants, would be necessary to develop a watershed model for the area.

For the microbiological parameters further study should involve the identification and relative abundance of disease causing bacteria. Further related studies in the region should be expanded to involve more sampling sites and additional water bodies for communities like Ekondo Titi, Buea, Muea, Nguti, Limbe and Tiko that straddle these water bodies to achieve more data from which policy makers can deduce a more informed decision. This would require more financial and logistical resources.

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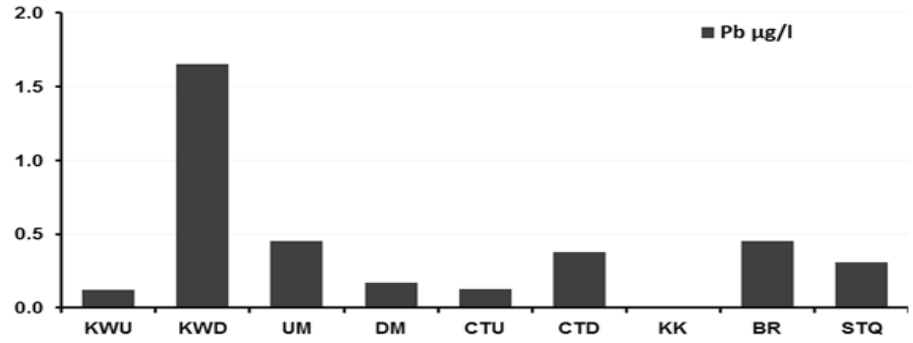
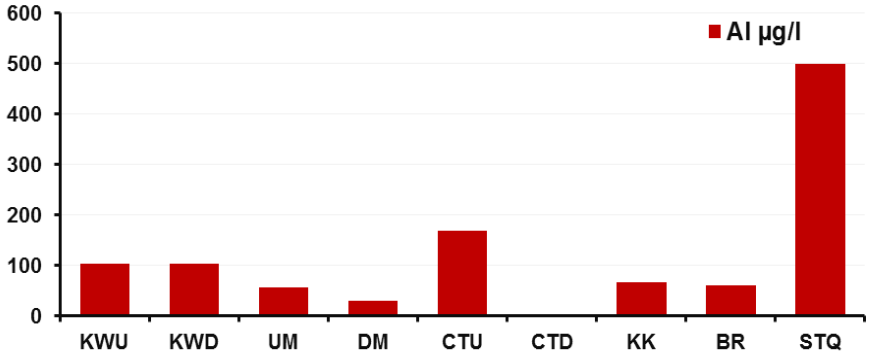
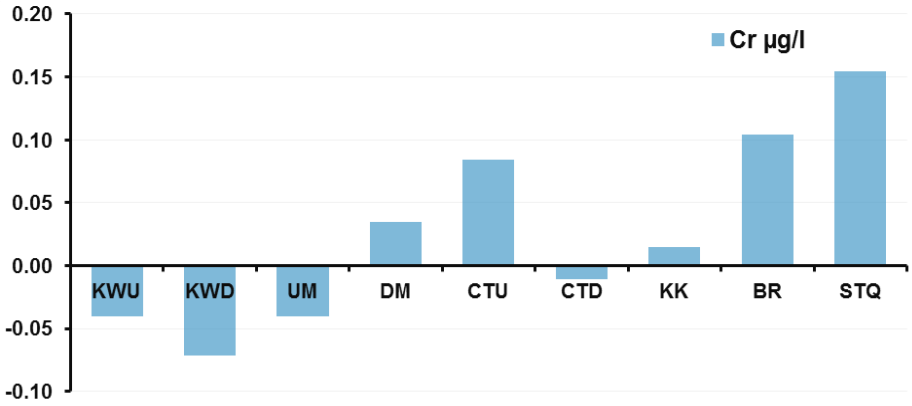
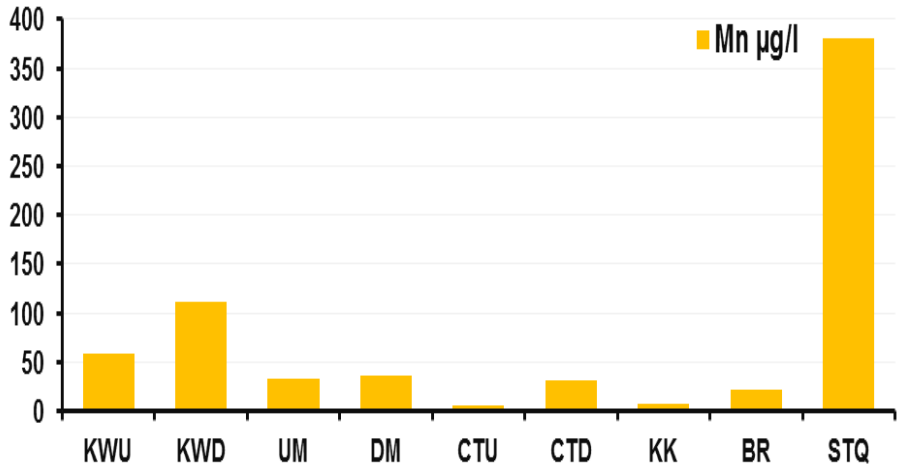
APPENDICES

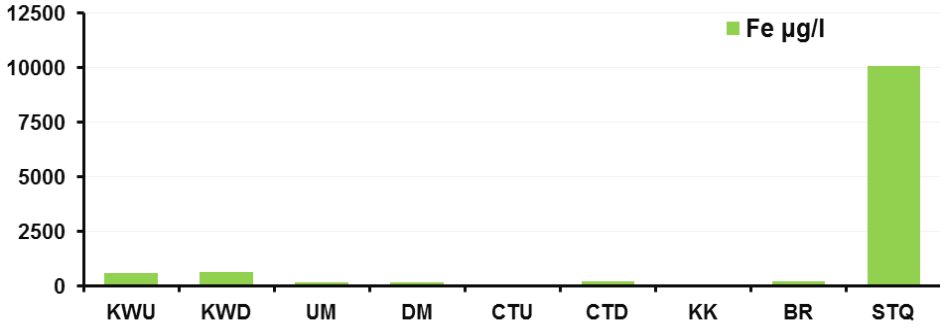
Appendix A: Histograms for Trace elements

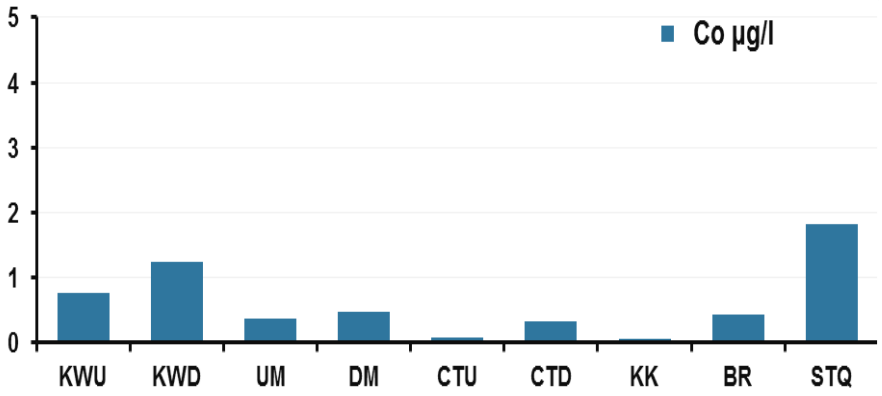


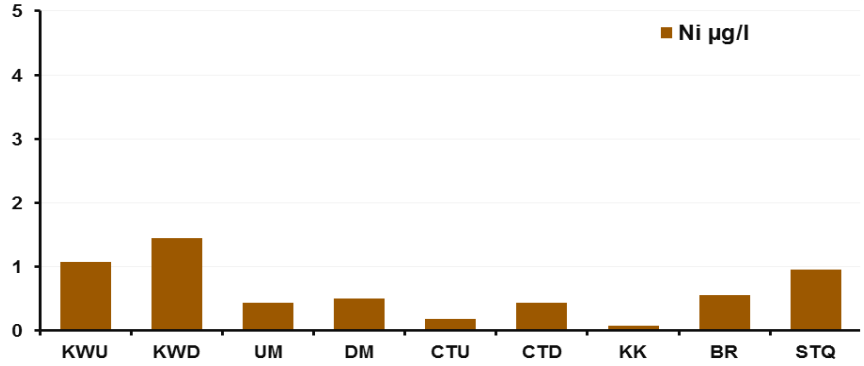


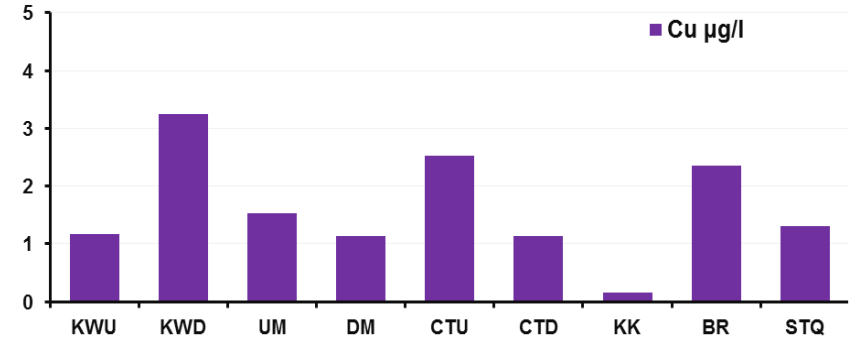


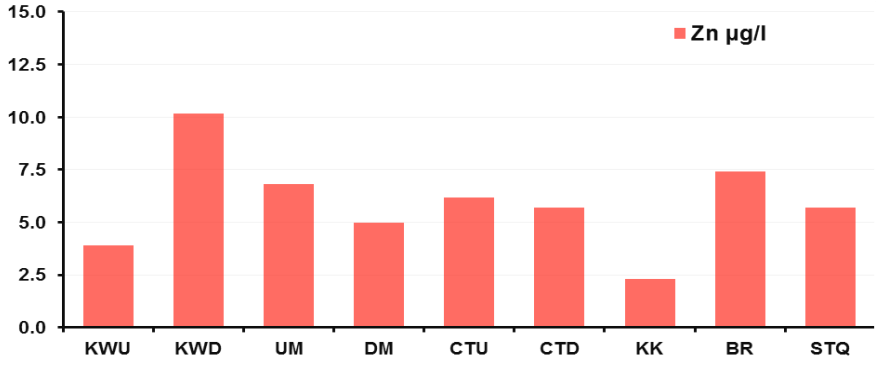

Mn µg/l
400
350
300
250
200
150
100
50
0
KWU
KWD
UM
DM
CTU
CTD
KK
BR
STQ

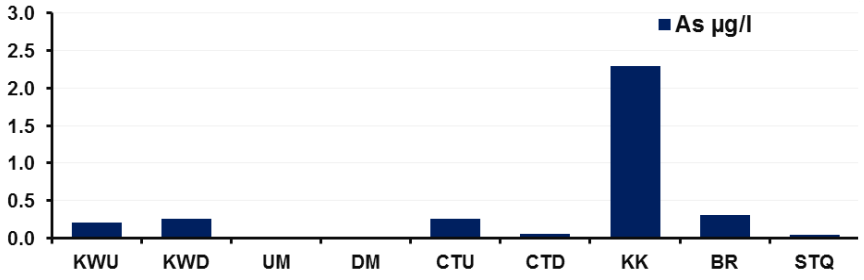

Fe µg/l
12500
10000
7500
5000
2500
0
KWU
KWD
UM
DM
CTU
CTD
KK
BR
STQ

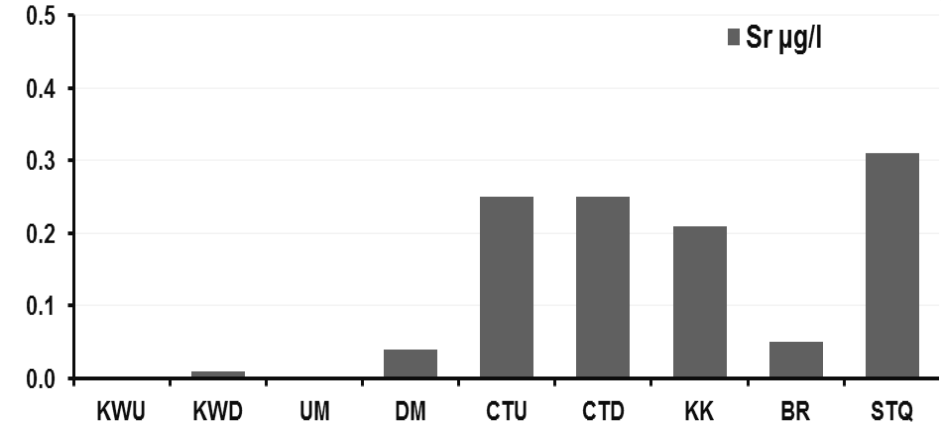

Co µg/l
5
4
3
2
1
0
KWU
KWD
UM
DM
CTU
CTD
KK
BR
STQ

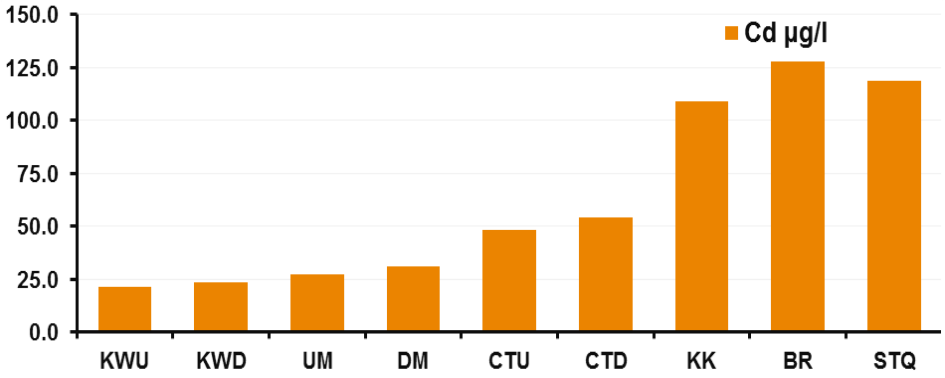

Ni µg/l
5
4
3
2
1
0
KWU
KWD
UM
DM
CTU
CTD
KK
BR
STQ

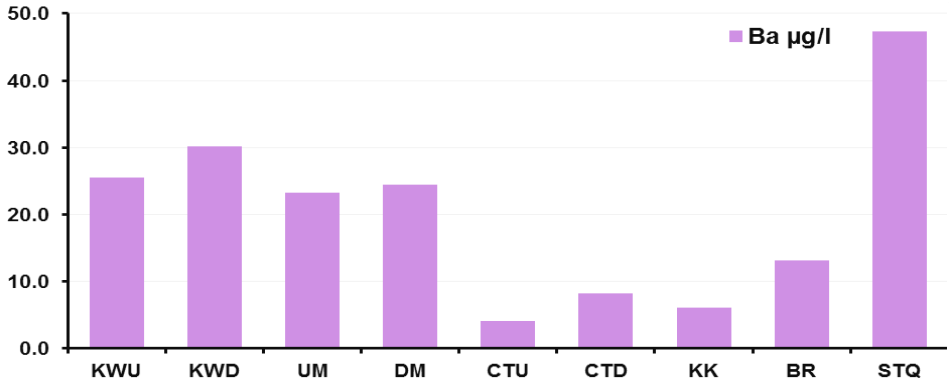

Cu µg/l
5
4
3
2
1
0
KWU
KWD
UM
DM
CTU
CTD
KK
BR
STQ


Zn µg/l
15.0
12.5
10.0
7.5
5.0
2.5
0.0
KWU
KWD
UM
DM
CTU
CTD
KK
BR
STQ

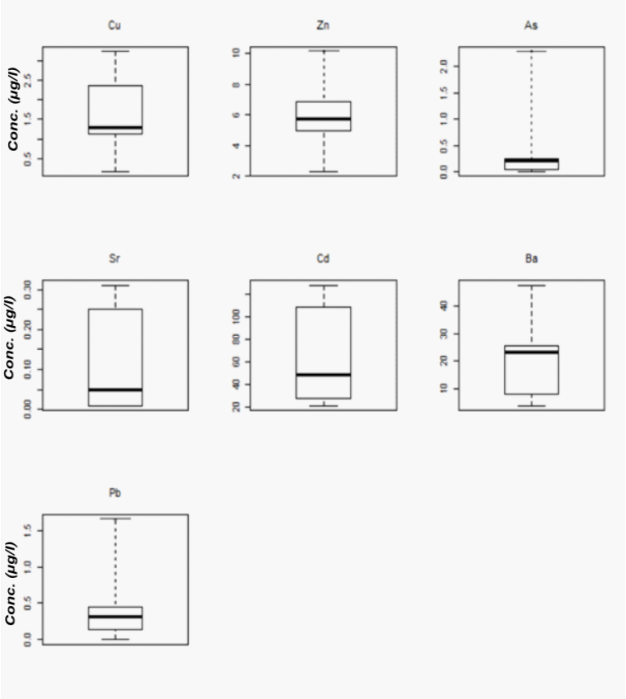

As µg/l
3.0
2.5
2.0
1.5
1.0
0.5
0.0
KWU
KWD
UM
DM
CTU
CTD
KK
BR
STQ

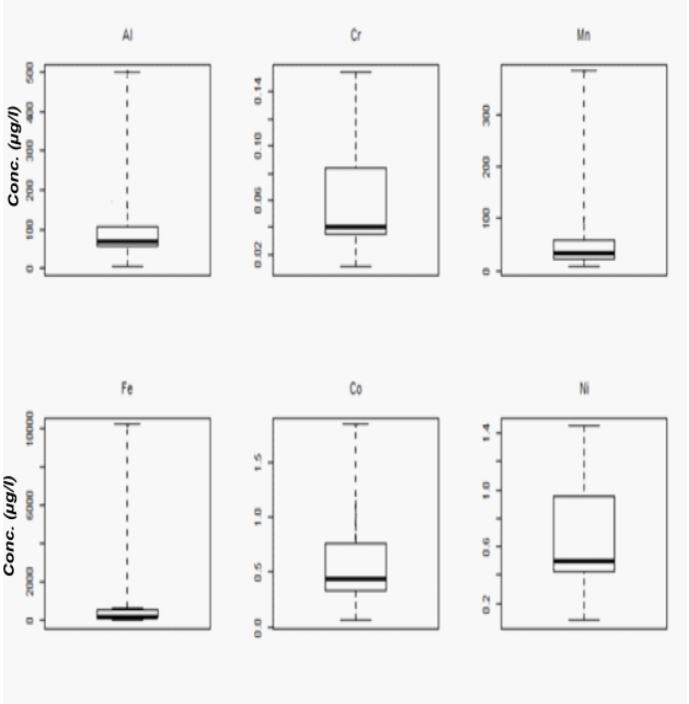

Sr µg/l
0.5
0.4
0.3
0.2
0.1
0.0
KWU
KWD
UM
DM
CTU
CTD
KK
BR
STQ

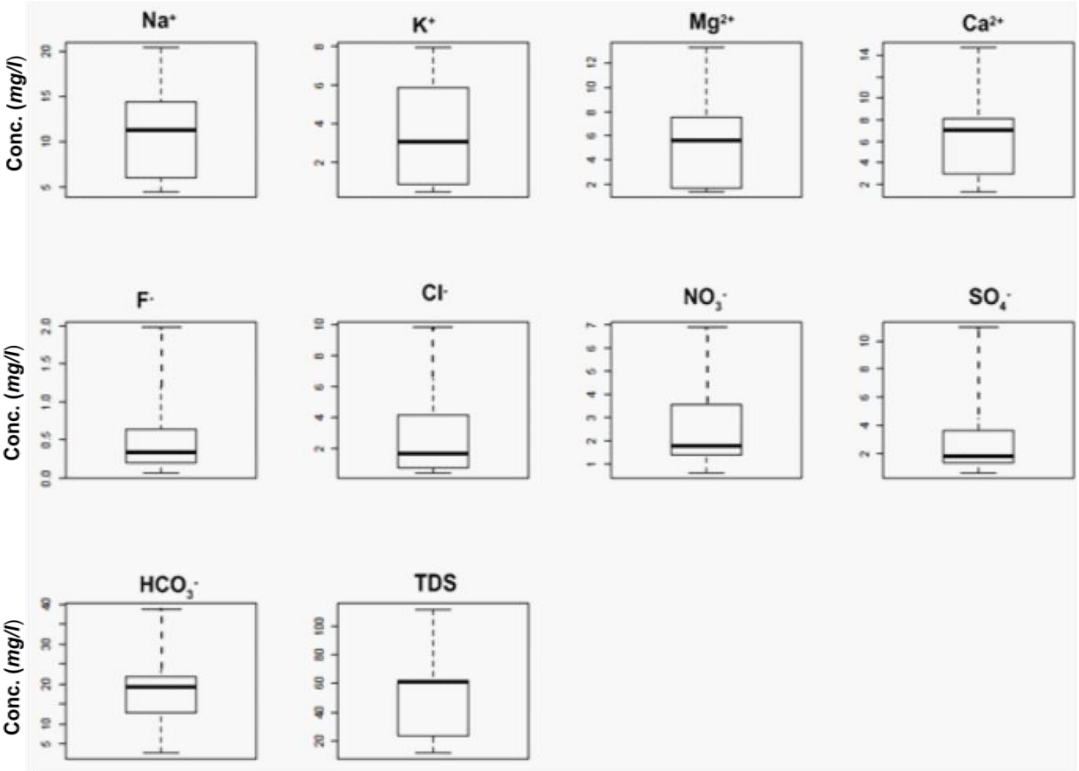

Cd µg/l
150.0
125.0
100.0
75.0
50.0
25.0
0.0
KWU
KWD
UM
DM
CTU
CTD
KK
BR
STQ

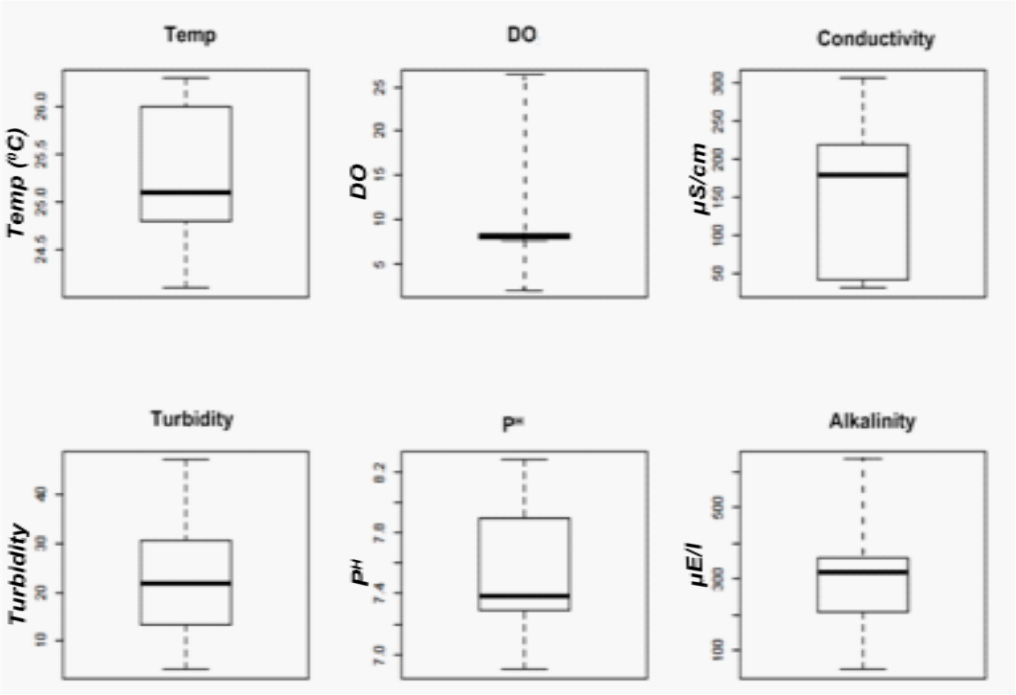

Ba µg/l
50.0
40.0
30.0
20.0
10.0
0.0
KWU
KWD
UM
DM
CTU
CTD
KK
BR
STQ

Appendix B: Box and whisker for all physico-chemical parameters








Temp
Temp (°C)
24.5
25.0
25.5
26.0
DO
DO
5
10
15
20
25
Conductivity
µS/cm
50
100
150
200
250
300
Turbidity
Turbidity
10
20
30
40
P^H
PH
7.0
7.4
7.8
8.2
Alkalinity
µE/l
100
300
500